

Daylight in façade renewal:

Using new metrics to inform the retrofitting of aging modern-era façade types

by

Edward O. Rice

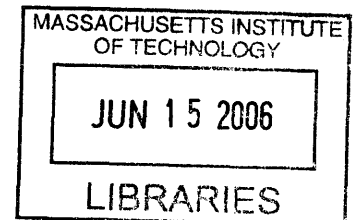
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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
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Daylight in façade renewal.

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ABSTRACT:

New methods for quantifying daylight are increasingly accessible to designers and planners. While these methods have enabled new building façades to better balance the admission of daylight with the maintenance of thermal control, they have generally not been applied to the existing building stock. This project uses these new methods of quantifying daylight to inform the renewal of aging façades on the MIT campus. The goal is to demonstrate how daylight analysis can inform the retrofitting process of prevalent modern-era façade types in need of renewal. The work shows how using these metrics in evaluating light access, façade type, and an array of retrofit measures in campus planning is helpful in understanding how intervention might enhance the use of daylight.

Keywords: façade, daylight, renovation, retrofit, lighting

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Prologue

There is great interest in daylight amongst designers. Daylight in architecture has always been regarded as both aesthetic and functionally important. There is also a growing interest in developing architecture which uses less energy and improves occupant well-being. Because daylight is part of the visual experience of architecture, it contributes to the value and marketability of real estate.

The dynamic and changing nature of daylight, which are at the core of its aesthetic value, also make it challenging to quantify the extent to which it can take the place of artificial lighting. This work explores new methods of quantifying daylight offered by the technical community that may be valuable to architects and planners.

A process of renewal is inherently sustainable, because it is based on re-use and adaptability. Renewal projects present opportunities and draw attention to issues that might otherwise be ignored by designers. By combining the visual aspects of daylight with the topic of renewal, I hope that architects and planners will be inspired to renew buildings in a manner that is exciting, healthy, and saves energy.

Acknowledgements

I am grateful for the help of Professor Marilyne Andersen, my advisor, who challenged me to produce work that is both relevant to other designers and at the same time based on realistic physics of daylight. I would also like to thank John Fernandez and Andrew Scott who provided constructive feedback throughout the process. The MIT office of planning and development supported this work by offering an internship to collect information on façades on the campus for use by the offices of development, planning, and maintenance. That information would later form the basis of the MIT campus buildings case study.

This work is dedicated to Mary, my fiancée who inspired me to pursue my interest in sustainable design in a rigorous way. I'm also grateful to the support of my family, Mom, Dad, and Margo who have always supported my endeavors, no matter where they have taken me.

I. Introduction

I.1 Daylight in the context of façade renewal

There exists a great opportunity in the architectural and engineering community. Vast portions of the built environment are reaching the end of their operational lifetimes. There are many reasons to consider the renewal of a building's exterior. Concerns about the rising costs of energy, insurance premiums, and keeping space occupied in competitive real estate markets all contribute to renewal decisions. Building owners often struggle with questions of when and how to upgrade an existing building's exterior.

While there are many issues involved in renewing building exteriors, this work focuses on the contribution of more effective utilization of daylight in that decision. An effective strategy for the utilization of daylight can improve the quality of the interior environment and save energy. Saving energy is not only an issue of cost. The building sector is responsible for 48% of all greenhouse gas emissions in the U.S. [Battles 2000] Global warming is a major incentive to reduce operational energy use in buildings.

Recent developments in advanced fenestrations allow façades to more effectively manage daylight, while at the same time avoiding the pitfalls of unwanted solar gain and uncomfortable glare. However, harnessing these technologies requires a comprehensive understanding of the photometric properties of daylight, the dynamic nature of the sky and sun, and the effective installation and commissioning of these advanced assemblies.

As this process is becoming more intricate, design professionals have become reliant on specialists to design and detail the systems. Large new building projects often have access to financing and, consequently a larger soft construction cost allocation that may allow the hiring of specialists or support a research effort¹. The renovation and retrofitting of older buildings gain less attention from the architectural and engineering community. Often, large institutions combine their capital renewal plans with a deferred maintenance budget. Fundraising for capital renewal projects remains more difficult than for spectacular new buildings that

¹ New York Times Headquarters building, Architect Renzo Piano, and daylighting research by Lawrence Berkeley National Laboratory is a current project which has utilized extensive daylight analysis in its design

provide high profile naming opportunities for private donors or corporate underwriters. Because the money is spread thin between so many interests, retrofit project budgets often do not support consulting fees for additional expertise in the area of daylight utilization.²

All the same, retrofitting is a huge part of the construction industry. In responding to a retrofitting program, designers may be responding to a desire of the owner to increase the present or future value of a building. There may also be a desire to adapt the building to a new use. “Sick” buildings, whose occupants are complaining of malaise and illness attributed to the building itself, create another type of mandate for retrofit. Many renovations are catalyzed by a desire to improve the interior environment or to solve a specific problem, such as an aging and problematic façade [Rey 2004]. There also can be a desire to reduce a building’s operational energy. Reducing energy has historically been less prominent as a reason for retrofit in regions which have enjoyed a relatively low cost supply of electrical energy. The financial motivation for enhancing daylight usually includes both a desire to save money on utility bills and to increase property value with bright, healthy work environments. It has estimated the duration of a retrofitting cycle to be 25-30 years, linked closely to the materials and methods utilized on the exterior [Rey 2004].

The majority of the US commercial building stock has already reached a renovation cycle. More importantly, the intensity of construction during in the 1960-1980s will bring an additional 25 billion square feet into a renovation cycle in the next 20 years. [CBECS 1999] The volume of US building stock in need of façade renovation is astounding. The American Institute of Architects’s Research Corporation estimated that in the next 30 years, half of the total U.S. building stock (residential and commercial), will be renovated. This was estimated at 150 billion square feet, which is equivalent to the total new construction predicted during this period. [AIARC 2000]

1.2 Daylight in the context of building energy consumption

The timing of daylight conveniently aligns with the other large electrical loads of a building. The most important electric load next to lighting is cooling, particularly during the hot summer months [Selkowitz 2001]. There is a capacity for daylight, when working in concert with the switching and dimming of artificial lighting, to significantly cut the electrical requirements during peak hours of energy use. It is important to discuss the quantitative impact of effective utilization of daylight. According to a 1996 report, electricity for lighting comprised more than a third of electricity usage for commercial

² Notes from interviews with members of MIT maintenance and planning departments

buildings [Vorsatz 1997]. There is great potential for improved use of daylight to offset these energy costs. Daylight has an inherent efficacy compared to artificial lighting. Daylight produces 100 lumens per watt of solar irradiation, while artificial lighting averages only 50 lumens per watt of building electricity. [Koster 2004] Daylight levels between 100 and 2000 lux provide useful illuminance that is bright enough to complete tasks with the human eye but not too bright to be considered glare [Nabil 2005]. There is a direct relationship between the periods of daylight illuminance and building energy consumption. A dynamic simulation method by Nabil and Mardaljevic described a close relationship between daylight illuminances which are considered useful (within the 100 to 2000 lux range) and the electrical energy required to light a building. The simulation results for 12 orientations and 14 differing climates indicates that electrical lighting energy required can vary by perhaps as much as 20 kwh/year/m² (1.8 kwh/year/Ft²) as a direct result of differing glass types alone. [Nabil 2005, pg 3].

Unfortunately, there currently exists a large stock of buildings whose designers placed little emphasis on daylighting. The 1950s-1960s marked a period of explosive growth in buildings, combined with an unprecedented implementation of large scale artificial lighting. Since that time, a few developments have chipped away use of artificial lighting energy in buildings. The most important of these are dimmable fluorescent ballasts and building integrated control, which have cut down on electrical requirements for artificial lighting for many buildings. Newer on the scene are daylight re-directive systems intended to bring light from side fenestration further into deeper floor plans.

The installation of daylight re-directive systems, in combination with automatic controls can have a dramatic effect on reducing artificial lighting requirements. A primary façade of the LESO³ building on the EPFL Campus in Lausanne was retrofitted with a standard glazed panel with high performance insulated units below an anidolic light shelf. This system, working in concert with automated artificial lighting dimming control, saves over 60% of the buildings electrical lighting energy requirements. [Burton pp.71] A case study of proposed changes to a façade of the Post Bank in Berlin compared daylight savings to the changes in energy required for HVAC. The project would have upgraded a highly glazed curtain wall⁴ with medium tinted monolithic glass units to high-performance insulated glass with a better visual transmission⁵ and daylight responsive controls with electronic ballasts. These measures alone saved 55% of the lighting energy required. The clear glass decreased heating energy requirements 12% but increased

³ LESO: Part of the Solar Energy and Building Physics lab at the Swiss Federal Institute of Technology

⁴ 63% glass to wall ratio with 1.45x 2.01 m insulated (U-Factor = 2.0, 0.66 Solar Transmission/0.44 Visual Transmission)

⁵ 78% Visual transmittance is the current limit for “high thermal performance” insulated glass units.

cooling energy 19% due to higher solar transmission.⁶ [Burton 2001 p77]

In the past, the use of daylight was often limited by the need to avoid unwanted solar gains causing unnecessary heating of indoor spaces. Materials that have the capacity to selectively admit light are now integrated into the elements of the most common façade manufacturing. In utilizing these materials, the designer releases the transparent wall of its tendency to entrap infrared radiation (i.e. heat) while allowing maximum daylight into the building. Even more advanced materials include angular selective films, polycarbonate prisms, diffractive acrylic profiles, and reflectors, which selectively admit light in a manner that is useful to the occupants and reject light that may be problematic. New technologies using highly insulating materials have created translucent façade elements with thermal transmission qualities similar to that of a solid wall (i.e. very low thermal conductance, or U-values less than 1.0⁷), while still transmitting light. Some façade experts even reach the conclusion that in some climates, conductive heat loss is no longer of great significance in new office buildings as a result of advances in glass technology and the generation of heat by office lighting and equipment [Campagno 1999].

1.3 The shortcomings of current design metrics for daylight

Some experts in the field of building physics comment on the need for architects to assess daylight parameters and to consider it early in the design process. Daylight specialists have long argued that any pre-design analysis should include climactic data, daylight and sunlight availability data and other usage measures such as utility rates and work schedules [Robbins 1986]. The reality is that, for lack of time or interest, architects rarely consider these parameters early in the design process. Given the high degree of aesthetic expression on the exterior façade, a building's skin is often conceived before experts have been engaged on the issues of daylight utilization. This limits the scope of daylighting solutions that are available to a project. In order to quickly reconcile economic concerns, most architects are forced to employ repetition and standard details. Certain architects do address the integration of daylight utilization early in their façade design. The vast majority, however, rely on the instruction of established codes and rules of thumb to make daylighting decisions once the form and order of the façades have been fleshed out.

⁶ Note: the blind systems were not improved as a part of this retrofit. The fact that the cooling increases with increased solar transmission shows how glass should be sought in conjunction with increased solar protections.

⁷ For reference the U value of single pane glass panel is around 5.8-6.0 W/mK (1.0 W/ft²K)

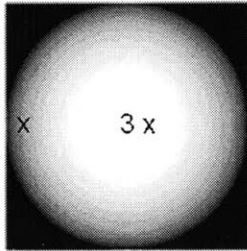


Fig 3
CIE overcast sky – A sky with luminance excerpted from Daysim manual materials, [Reinhart, IRC, NRCC 2005] This sky model is the standard for making daylight factor calculations for daylight code compliance.

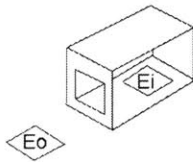


Fig 4
Daylight factor calculation
Ratio of interior (E_i) to exterior illuminance (E_o) $E_i/E_o \times 100\%$ measured with a sky for the overcast sky condition.

In the United States, there is no codified mandate for the use of daylight in work spaces. Some have argued that there is resistance to the allowance of daylight credits in building codes and regulations in this country out of a belief that savings “cannot be guaranteed.” [Reinhart 2004] Currently, the Leadership in Energy and Environmental Design (LEED) structure will grant only one point (out of 69 possible points)⁸ for a plan that has 75% of the interior space receiving a daylight factor of 2% or better [LEED 2000].

Not only does the LEED structure allocate inadequate value to the use of daylight in environmentally sound design, the metric by which LEED measures daylight utilization, the daylight factor, may be problematic. The daylight factor is the percentage of light arriving on a horizontal surface inside a space relative to the amount measured on the exterior of a building. A uniform overcast sky model is used for these calculations. As a result, the façade designer is left to design the opening daylight admitted under overcast conditions, even when later they are forced to use a lower solar heat gain coefficient (darker glass) due to the large glass area. Adding too much glazing may increase heating and cooling requirements. The daylight factor calculation does not take orientation into account. Consequently, glass may be located in problematic locations with high probability of glare from direct sun. The contribution of the window geometry itself is not taken into account either. For example, a recessed opening contains within it a form of integral multi-directional shading that will both reduce unwanted solar input and enhance admitted daylight. But a design using strategically placed openings receives no credit in the LEED system.

The research community has proposed the concept of daylight autonomy as a more accurate metric for daylight utilization. An integration of this concept into the value systems which designers currently use for “low energy or sustainable” design will have four distinct advantages.

First, it will allow for a closer connection between daylight utilization and the savings of electrical lighting energy. Most proposals for new metrics define the concept of daylight autonomy, as the percentage of time for which there is little or no need for artificial light. Since daylight autonomy is based on time (the working hours) and a quantity (usable light level) and is an indirect measure of lighting energy required. Different variations on the concept of daylight autonomy have been proposed for quite some time in the technical community. One largely accepted definition for daylight autonomy is the quantity of time (expressed by a percentage of all standard operational hours of a building) for which the horizontal task plane receives a pre-defined illumination (usually 500 lux for office work)⁹ without the need for

⁸ This is the only point linked directly to daylight quantified by the daylight factor. Another point is rewarded for allowing views to the exterior.

⁹ Some have proposed standards as low as 100 lux ref: [Nabil 2004]

artificial lighting. Others have suggested variations based on the same principles.

Secondly, daylight autonomy calculations take into account the orientation of a façade. Façade orientation is a major determinant of daylight levels, yet can be ignored in important design and materials decisions. For example, in typical practice, a building services engineer determines the cooling load due to solar radiation, taking into account the orientation of the façade. Then the same designer chooses a shading coefficient (G-factor in Europe) to manage the cooling load. The architectural plan usually calls for a similitude of glass types across all façades, so the same selected glass type is utilized for all façades and orientations. By accounting for façade orientation, the use of daylight autonomy in the design process may inspire innovative approaches to the design of the building envelope.

Third, it will acknowledge that direct light can be a component of a sound daylighting scheme. A large category of daylighting strategies involving re-direction or scattering are based on the assumption that direct light, when steered away from the task plane, can be put to work deeper in the building. The daylight factor is based on an overcast sky model and does not account for direct light. The designer typically assumes that direct light should be rejected at the building envelope and is not usable to illuminate spaces further than 4m from the perimeter. Direct light utilization must occur carefully in avoidance of solar gain and excessive glare, but it provides an enormous potential for improvement in deeper plan spaces. In a retrofit of an office plan deeper than 4 meters (13 ft), a well-managed direct light component can be of great benefit. New materials and methods to redirect, scatter, and diffuse direct light are designed to ensure that daylight can be steered away from areas where it will cause glare. Needless to say, it is quite difficult to use these principles of re-directing and scattering direct light while designing with a metric based on the overcast sky.

Fourth, the use of daylight autonomy will encourage the design of solar protections earlier in the design process. Newer automatic fenestrations are often based on a timed system linked to the path of the sun. These systems ensure maximum entry of daylight during usable illuminance ranges, but provide shade at times of glare. These fenestrations can also redirect and scatter light as discussed above. Self shading façades and fixed protections have been a part of buildings for years, but newer automated fenestrations must be evaluated in the planning process in order to ensure that they remain part of a project budget. Currently, no widely used guideline exists for estimating the impact of manually operated shading [Reinhart 2004]. The daylight factor calculations do not take the benefits of shading into account, because the use of blinds, both automatic and manual, are linked to glare and direct sun. Daylight autonomy metrics would capture these benefits and encourage the use of automated fenestrations.

Recently, building energy codes in the US have started to acknowledge daylight as a resource. In the Massachusetts Energy Code, the “Daylighting Control Credit” allows one to downsize the electrical power budget for a lighting zone (from 1.8 to 1.5 watts/SF) if there is a daylight sensing system [ECC 2000]¹⁰. The allowed skylight area may be increased if a shading device that blocks half of the solar gain is present on the façade.¹¹ More importantly, special accommodations for clear glass and increased glass area are made in the code for façades whose indoor spaces are identified as “Perimeter Daylighting Zones,”¹² equipped with sensors and dimmable fixtures [MEC 2000]. The code allows an increased window to wall ratio of nearly 100% under the condition that the U- factor is lower than 0.72 w/ft/F (4.3 W/m²K SI) and the visual light transmittance is greater than the shading coefficient. This encourages the use of high performance glazing panels attaining a high transparency while maintaining good thermal control.

The daylight factor does not have the sensitivity to assess the kinds of advanced solutions that are needed for daylight management in new and retrofitted projects today. As Nabil wrote, “The venerable daylight factor approach is now over fifty years old. It persists as the dominant evaluation metric for daylighting because of its inherent simplicity rather than its realism” [Nabil 2004 pp1]. There is great opportunity for the design and technical communities to transition to improved design metrics, including daylight autonomy, for the effective utilization of daylight.

1.4 The value of approaching daylight as a resource in facilities planning

In planning for the future, large stakeholders in the built environment, such as universities, hospitals, government campus groups and corporate headquarters, must often consider façade renewal. The cycles of ownership for such institutions, which consist of multitudes of buildings, usually exceeds 100 years. Included on their agenda are maintenance costs, operational energy, insurance issues and the health and well-being of building occupants.

Managing and operating aging, existing buildings is typically a larger part of an institutional budget, and a larger part of the role of a facilities planner, than new construction. Maintenance and operational cost of a commercial building is 5 times that of first construction cost [Evans 1998]. In many cases, the cost of a major exterior renovation may exceed that of demolition and new construction. [Evans 1998]. The cost of relocation is often significant when combined with the rising price of

¹⁰ Referenced in item 402.3.1 of MA Energy Code concerning electrical lighting power density

¹¹ Referenced in 402.3.1b of MA Energy Code concerning skylight area

¹² In table 402.4.1.2 of MA Energy Code concerning the ratio of fenestration to solid wall

land. These factors indicate the special value of a façade retrofit which allows normal operations to continue. They also re-affirm the need for planners and architects to understand the potential of improved utilization of daylight, so that it may be integrated into plans for building renewal.

There is an economy of scale in institutionalized renewal. With the wave of 1950s and 60s-era buildings in need of retrofit, large multi-building institutions have an opportunity to be at the forefront of incorporating daylight autonomy in façade renewal. Some of the hidden costs in the development of advanced fenestrations can be reduced by the large volume of façade area produced for these projects. There is an “inevitable” rise in cost that accompanies the extensive engineering and product involvement of advanced façades, and one expert recommends using standardized kits of parts to reduce costs [Selkowitz 2001]. This is increasingly feasible, as façade element manufacturing is consolidating into larger firms that are responsible for the majority of façade construction worldwide. Manufacturers now provide services for both the design and construction of façade solutions in an effort to keep up with demand for advanced envelope designs of combined elements. Large institutions are well-positioned to take advantage of their scale to retrofit aging buildings with energy-saving façade solutions that improve the daylight autonomy of the indoor environment.

1.5 Problem statement

Due to limitations in budget, time, and a general lack of awareness amongst owners and design professionals, most façade renewal occurs without the benefit of advanced metrics which support the improved utilization of daylight. There currently exists no generally-accepted means by which to measure the use of daylight in building or façade design. The current LEED standard of the “daylight factor” is overly simplistic and does not capture the energy benefits of daylight redirection and shading. However, better measures for assessing daylight utilization, such as daylight autonomy, do exist and have been validated. The US has a large volume of aging buildings in need of façade renewal that have very poor daylight utilization. There is great opportunity to save energy and improve the quality of the indoor environment through intelligent façade renewal that is guided by appropriate daylight metrics, such as daylight autonomy. Large institutions, including university campuses, are in an ideal position to be at the forefront of incorporating daylight analysis and fenestration solutions in the renewal of aging façades.

2.0 Methodology

2.1 Using MIT campus buildings as a learning tool

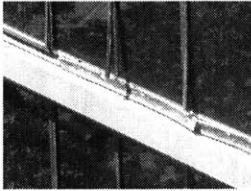


Fig. 5 Building 36,
Progressive failure of
glass fixing system
Photo:ER

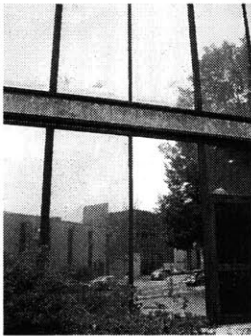


Fig. 6 Building 36,
Weathering of early
metallic coatings after
30 years in service
Photo:ER



Fig. 7 Building 16,
Curtain wall system
Photo:ER

Often, in making proposals for new buildings, designers do not establish goals for daylight and a façade design. Dealing with daylight in preliminary design is hindered by the existence of a wide array of variables affecting daylight utilization. A designer is left to wonder whether to change the space configuration, change the façade, or re-orient the building. The daylight factor, to some extent, simplifies some of these uncertainties by disallowing various inputs. This work substitutes advanced metrics in the daylight factor's place in order to evaluate the daylight utilization of a specific group of façades. These façades are emblematic of the materials and technologies utilized from 1940-1980.

When working with existing buildings, the variables are restricted somewhat. For example, a group of buildings in a certain location present a series of façade types and orientations, and an existing space configuration beyond. On the MIT campus there are many buildings which could benefit from improved utilization of daylight, some are in more immediate need of façade work, but renewal in some form or another will be contemplated for all of them. There is a clear need to address renewal and in a manner which gives daylight utilization its fair share of attention. By studying the MIT buildings with new metrics there is a hope to gain insights into similar buildings elsewhere. It is also important that the work be accessible to not only the MIT planning community but also others who may face similar tasks.

There are two ultimate goals of such work. First, it serves to elucidate current technical research on advanced daylight metrics for architectural designers and planners. Secondly, it serves as an aid in the renewal and retrofit process by providing a ready-made catalogue of information concerning familiar façade types.

2.2 MIT building study group

This work identifies buildings built between 1940 and 1980 on the M.I.T. campus that exhibit typical modern-era façade types. Common patterns in façade design during the modern movement enable this work to be applicable to similar façades elsewhere. Pre-cast concrete panels with punched openings, poured-in-place concrete frames and infill walls,

curtain wall, heat absorbing glass, and applied solar films are examples of modern-era façade solutions that have aged 50 years or more.



Fig 8 Study scope
MIT central campus
area showing buildings

Specific information about these façades on the MIT campus was gathered by the author as part of an independent project in the summer of 2005 with the MIT Offices of Planning and Development, Operations, and Engineering. The work focused on the exterior envelopes of a group of buildings 25-75 years in age and identified exteriors most in need of renewal. In assembling this information, the chief objective was to provide evidence-based decision-making and planning for inevitable façade renewal. This work was of interest because ongoing maintenance on building exteriors incurs significant costs and façades are directly related to buildings' energy consumption. Similar planning work has been previously undertaken on the older buildings.



Fig. 9 Building 36,
MIT campus, Architect
Walter Netsch of SOM
Photo:ER

In each case, selective renewal (i.e. the replacement of certain parts and/or components) will be compared to transformative renewal (i.e. the complete replacement of the façade). Specific considerations will include the reduction of building operational lighting requirements, and qualitative improvements made to both the interior and exterior.

In order to focus on the issue of daylight, a sub-group of 11 buildings within the central campus area was selected. Their completion dates range from 1950 to 1980. These buildings are all utilized for laboratory, faculty offices and classrooms. Unlike residential buildings, these buildings are continuously occupied during daylight hours, and the vast majority of their assignable area relies upon glazed façades for daylight rather than courtyards, clerestories, or skylights.

The first major group of fenestration systems could be defined as “curtain wall” or a metal system which combines vision glass panels and opaque metal spandrel panels. There are two distinct types existing on



Fig. 10 Wood frame infill set inside exposed concrete columnnade Photo ER

three buildings. Buildings 16 and 56 have hollow steel mullions and window frames, plate glass, and metal pans spandrel panels filled with insulation. Building 26 was designed by the more notable Gordon Bunshaft of SOM. Its façade differs slightly in the use of aluminum trim over a steel system underneath.

A second system is the punched opening recessed in a pre-cast glass panels. This glass system apparent on the concrete buildings 54, 66 and 18, are all the work of architect I.M. Pei. In the Pei buildings, the system consists typically of plate glass directly glazed into concrete surround, with a removable wood sill in some instances. Replacement of this system is difficult due to the limited sizes of manufactured insulated glass and the dimensional limitations of the glazing recess cast into the concrete.

A third prevalent system is the exposed concrete frame with an in-filled window system within. A variant of this approach, recesses the window system further .6 m (2') beyond the façade behind an external concrete frame. This recess functions as an integrated shading device so it is considered as a fourth distinct type. These two systems are evident in buildings 09, 13, 36, 37, 38 and 39, all designed by Walter Netsch of SOM. The systems proportioning consists of approx 2'-2" by 8'-0" tall glass modules fixed by 8"x 2 1/2" solid mahogany mullions which have been painted black.

Of all the buildings in the study, those that have wooden fixing systems within exposed concrete frames have the widest variety of problems. Approximately half of them are in a more serious state of deterioration, and require on-going preventative maintenance. The most common cause for concern is the deterioration of wooden glass fixing elements caused by wetting and drying cycles.



Fig. 11 Building 54, MIT Campus Punched openings in pre-cast concrete panels Photo:ER

2.3 Method of studying daylight utilization

The daylighting implications of façade typologies are investigated by modeling side-lit work spaces. The floor space is divided into increments, or zones, that correspond to both interior space planning units and artificial lighting. Zones measure 3 m (10') which roughly correspond to the space occupied by one person in an open plan office or lab. This depth also corresponds to the floor space normally illuminated by a single fluorescent lighting fixture.

Fig. 12

- a. floor plan section corresponding to a typical façade 'module'
- b. useful space planning increments

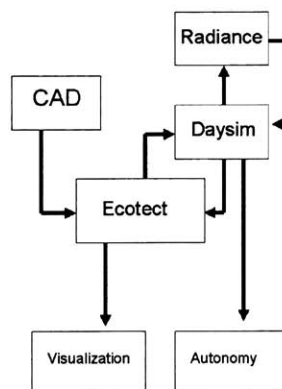
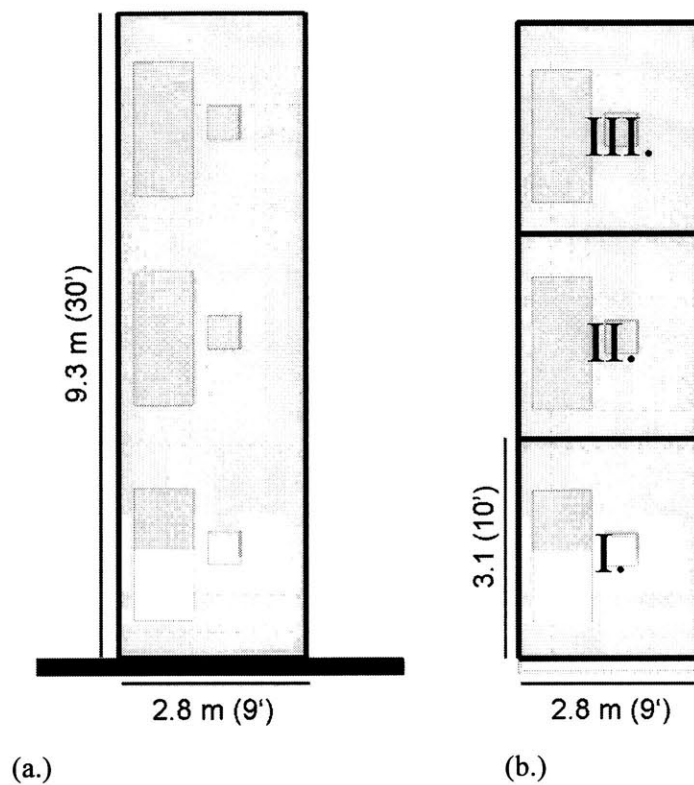


Fig. 13

Work flow diagram indicating software utilized

2.4 Daylight simulation method

Daylight autonomy is calculated through a series of simulations made under a variety of sky conditions. A computer-based simulation utilizing the Radiance lighting simulation core was chosen as the basis for calculating hourly daylight levels. The Radiance program has been validated as an accurate method of simulating daylight [Walkenhorst 2002]. The Java based program Daysim, developed by Christoph Reinhart at the NRCC¹³, interfaces with the Radiance program to generate energy savings and daylight autonomy percentages, based on output from Radiance. Daylight autonomy is defined as the percentage of normal working hours (8am to 5pm, M-F) at which 500 lux is exceeded in the task plane.

¹³ National Research council of Canada

The Daysim software divides the celestial hemisphere into several “disjoint sky patches” and then calculates how each sky patch contributes to the illuminance at a single point in the building.

The program completes a full set of daylight coefficients for a given sensor point with respect to all sky segments and the building geometry. The total illuminance at the same sensor point is calculated through a superimposition of the data to a chosen sky luminance distribution based on a given weather data set [Reinhart, 2000]. The daylight coefficient approach was validated by Christoph Reinhart who compared it against a reference case and various simulation methods [Reinhart, 2000]. In the validation study, Daysim was found to be superior to previous methods in most simulation runs, primarily due to its utilization of a more accurate Perez luminous efficacy sky model¹⁴ combined with its capacity to take more detailed account of both direct and diffuse illuminance values for each time step. [Reinhart 2000]

$$DC_{\alpha}(x) = \frac{E_{\alpha}(x)}{L_{\alpha} \Delta S}$$

Fig. 14

Definition of Daylight coefficient for

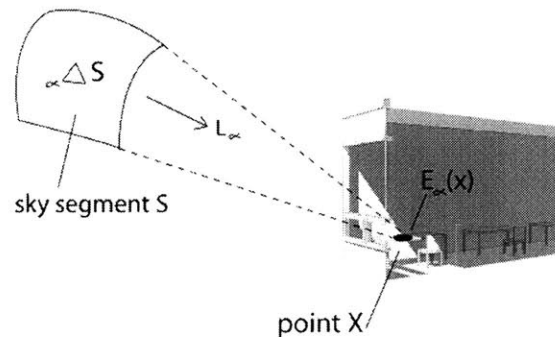
X= any sensor point inside

S= one of various sky segments

E= illuminance

L= luminance

[Reinhart 2000]



practical standpoint, the daylight coefficient approach is less calculation intensive. For a given architectural geometry, a series of coefficients can be calculated. This series of coefficients then contains all of the geometric and material information of a model. After this information is calculated, variations of the sky illuminances based on weather, latitude and the sun position for every time step can be fed across a series of daylight coefficients. The end result is a record of illuminances for every time step of the simulation period. The weather data in Daysim is based on a typical meteorological year (TMY format) for the specific geographic location modeled [Reinhart 2000]. Another aspect of Daysim that proves invaluable is its capability to simulate various blind usage patterns. This differs from other software, which often uses an “all or nothing” method of accounting for the manual or

¹⁴ The Perez sky model validation can be referenced in R. Perez, R. Seals, J. Michalsky, All Weather model for sky luminance distribution- preliminary configuration and validation, Solar Energy 50 (3) 1993 235-245

automatic operation of blinds. By making assumptions concerning the responsiveness of the model (i.e. automatic mechanisms vs. passive users who do not move the blinds), the program is able to make more realistic predictions of the contribution of automatic systems.

The software Ecotect V5.2 was used as a modeling and visualization tool. In all cases models were generated in Ecotect V5.2 and exported to Daysim and Radiance for simulation. The results were brought back into Ecotect for visualization. The appropriate weather data set (TMY format)¹⁵ for the Boston climate was used as a basis for the direct normal, and indirect normal irradiance levels on an hourly time step for the year.

2.5 Exercise 1: Urban light access

The first exercise in this project simulates how shading from other nearby buildings affects daylight autonomy. In order to study the issue of daylight access in the selected group of buildings, a 3D massing model was constructed of the entire central MIT campus area. A test room measuring 9.3 m (30') long, 2.8 m (9') wide, and 4m 12' high was then located at a variety of locations inside the model. Test rooms were modeled in each of the 7 buildings in extremes of exposure and shade and in all façade orientations. For purposes of this simulation, all façades were assumed to have (55%) window area. The window glass was assumed to be void (no reflectance, 100% transmission). All interior materials were assumed to have uniform 60% reflectance. No provision for blinds was included in this model. The Daysim software was used to generate basic illuminance profiles and daylight autonomy at three points (one at the far center of each of the three space planning zones) within each room. Each test point is 2.1 m (7ft) from the façade or adjacent zone. Daylight autonomy is defined as the percentage of working hours between 8:00 AM and 5:00 PM for which there is more than 500 lux illumination on the task plane within the room, requiring no artificial lighting.

¹⁵ TMY = Typical Meteorological Year, Data from Boston Massachusetts

Fig. 15

Basic simulation test
room dimensions

- a. opaque façade elements (0.5 r)
- b. void
- c. room walls (0.5 r)

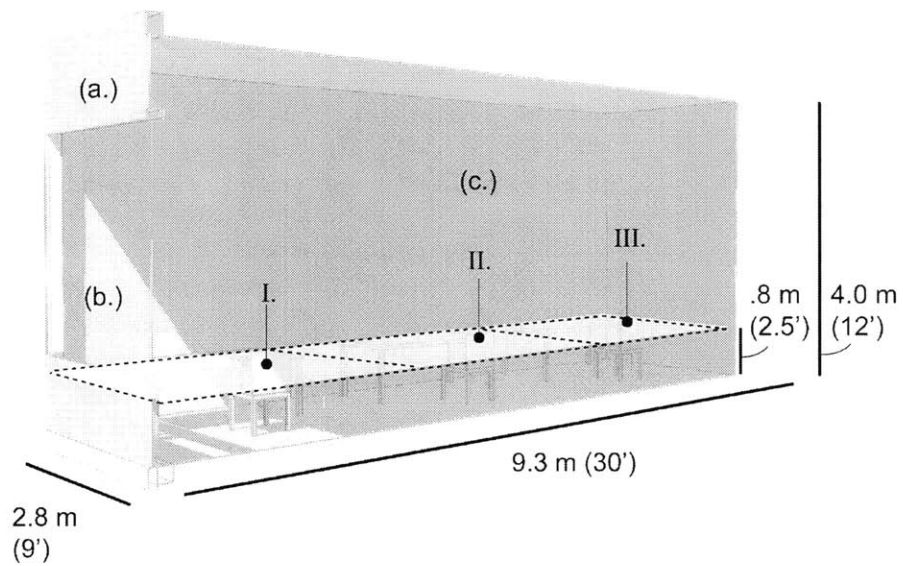


Fig. 16a

Central MIT campus
light solar access
model – Model image
is overlaid with
Ecotect's included
particle trace method
for estimating
cumulative solar
irradiation on façade
surfaces over a yearly
period

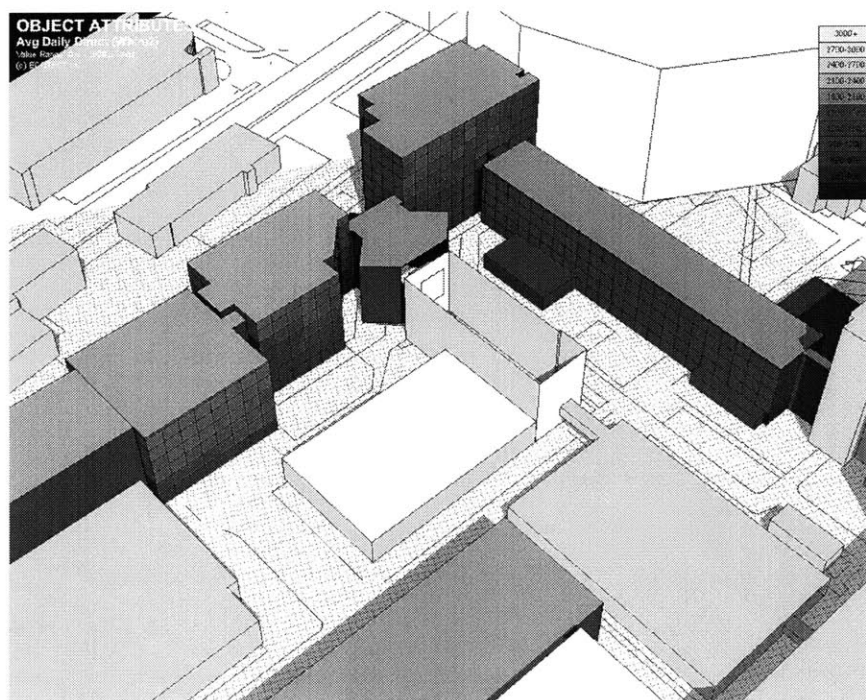
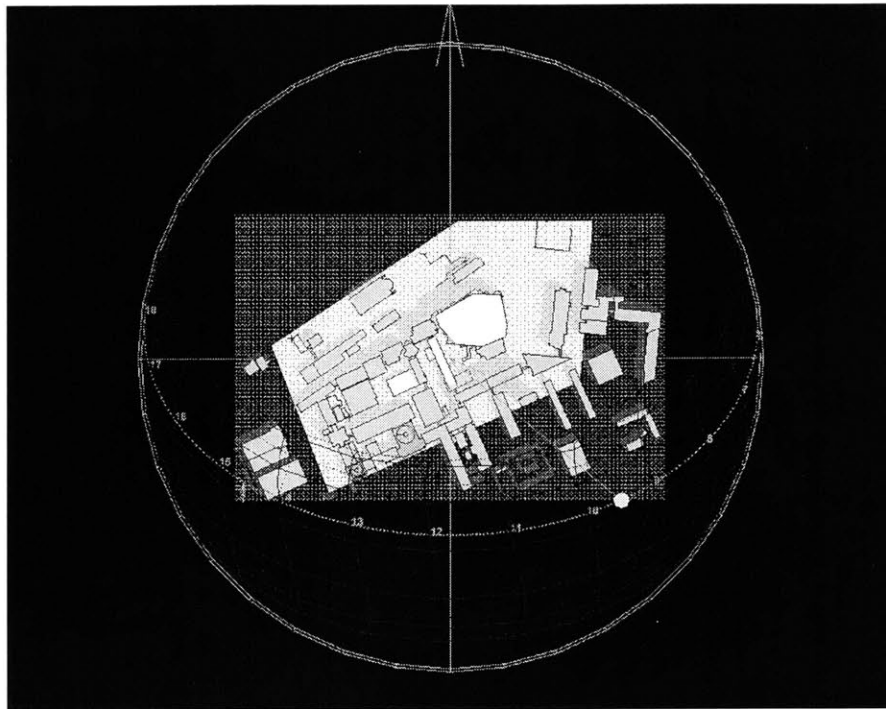


Fig. 16b

Plan view of model
with overlaid sun
course showing
buildings modeled in
order to simulate urban
masking.

*Image produced
Ecotect software*



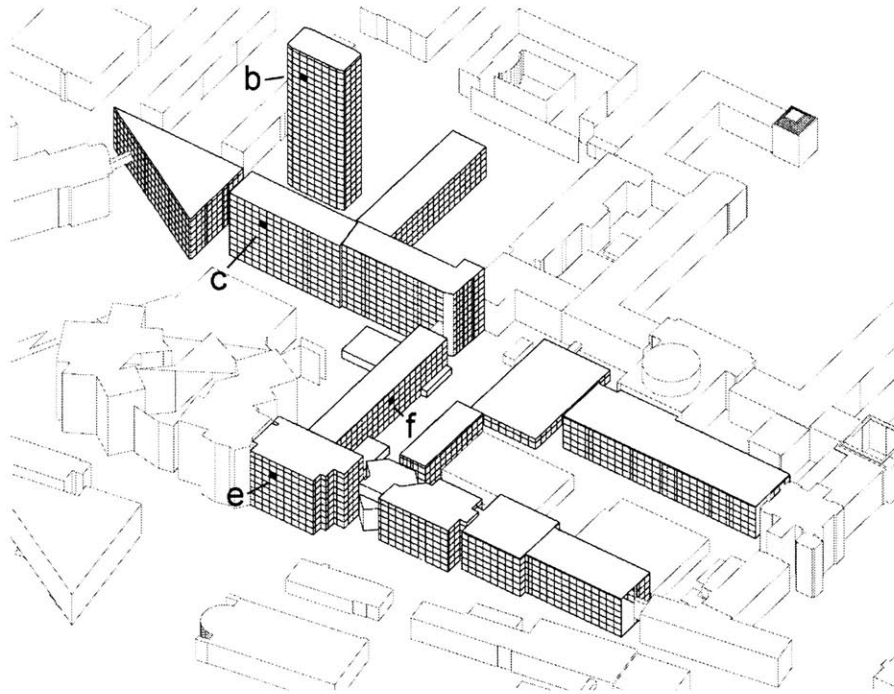


Fig. 17
Southeast view
showing sample room
locations

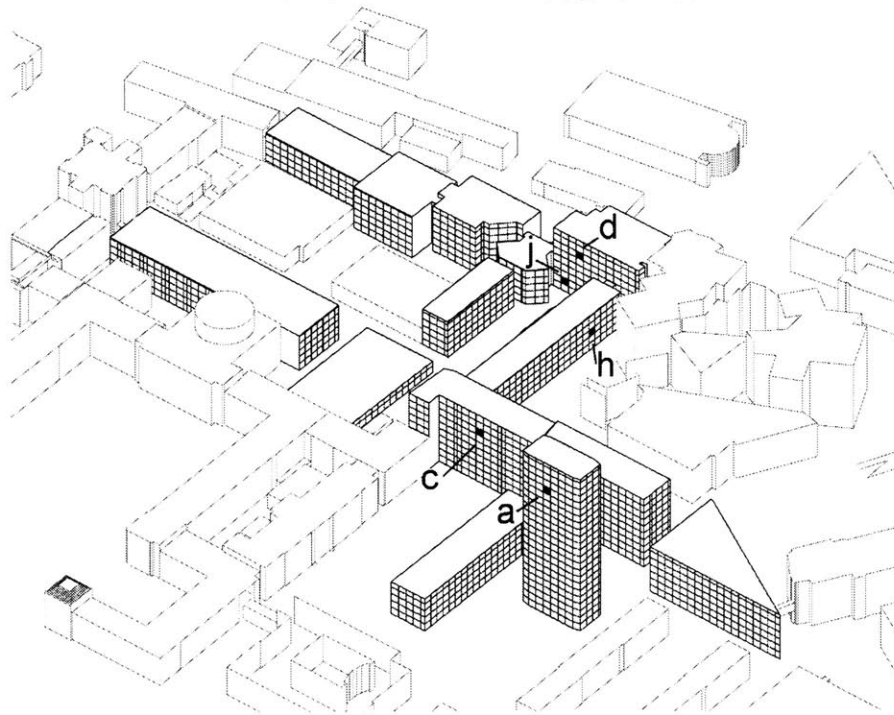


Fig. 18
Northwest view
showing sample room
locations

2.6 Exercise 2: Façade typologies

The purpose of the second simulation exercise is to determine the contribution of façade type to daylight autonomy. In this second investigation, the four prevalent façade typologies were modeled in all four orientations. Daylight autonomy was calculated separately for each orientation and also averaged for all four orientations and through the depth of the test room space (all data points in zones 1-3). This placed equal weight on each orientation and each depth level. The daylight factor values for the four façade types are also calculated using the method referred to in the introduction. The same typical room dimensions were utilized as in the prior analysis (see fig 15). In each of the four cases, the façade geometries and materials were included in the model.¹⁶ The glass was assumed to have the same characteristics in all cases (50% visual transmittance glass) in order to focus on the daylight admitting properties inherent in the size and aspect of the opening, glass fixing methods, and overhangs. In reality, the visual transmittance of the existing glass varies between 40 and 50%.¹⁷

¹⁶ A more detailed description of each façade type is included in the appendices

¹⁷ Based on field observations of author (see appendix B) for notes on illuminance levels taken inside buildings compared to exterior levels

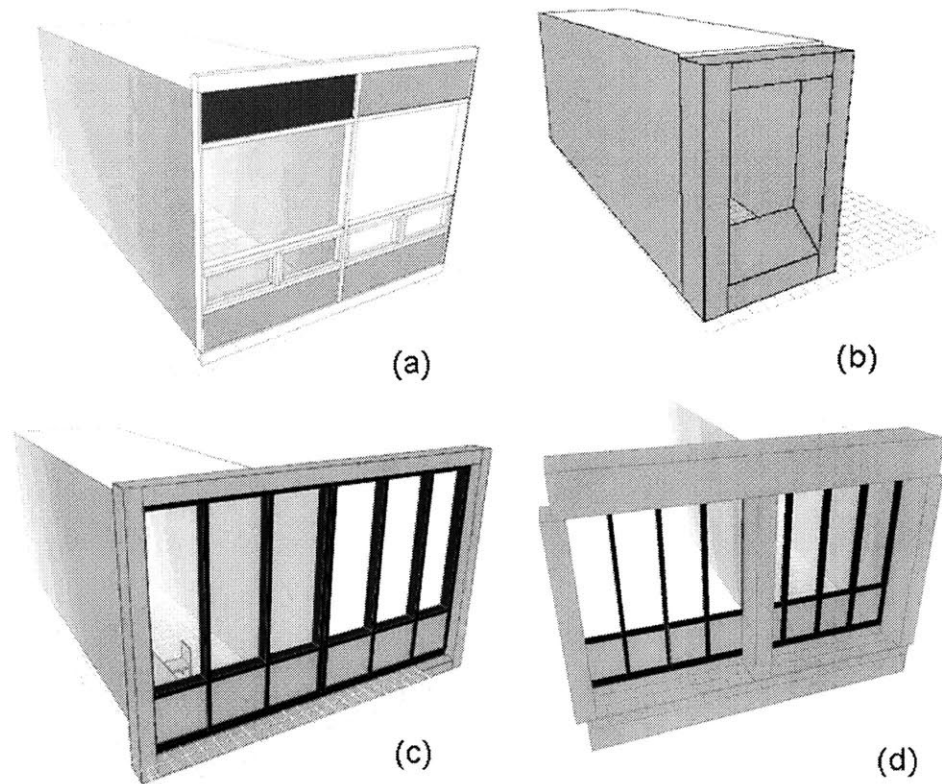


Fig. 19
Façade types
a. Curtain wall
b. Punched opening
c. Flush frame and in-fill
d. External frame and in-fill

Percentage of Façade section that is glazed, not including mullions or spandrel panels.

Table 01
Comparison of
glass to wall ratios
for various façade
types

a. Curtain wall	53%
b. Punched opening	42%
c. Flush frame and in-fill	72%
d. External frame and in-fill	67%

Each of the four types was then simulated on all four orientations to generate levels of daylight autonomy. The resolution of sampling included was a (4x10) sample point matrix located .8 m off of the floor. This resolution is much higher than that of the previous simulation, and enables the generation of graphic visualizations of the distribution of autonomy into the room. The final results can also be expressed as a numerical average per zone. When comparing these visualizations with ones generated with the daylight factor, (see fig 20 below) the daylight autonomy metric gives a more detailed description of the façade's contribution to daylight utilization.

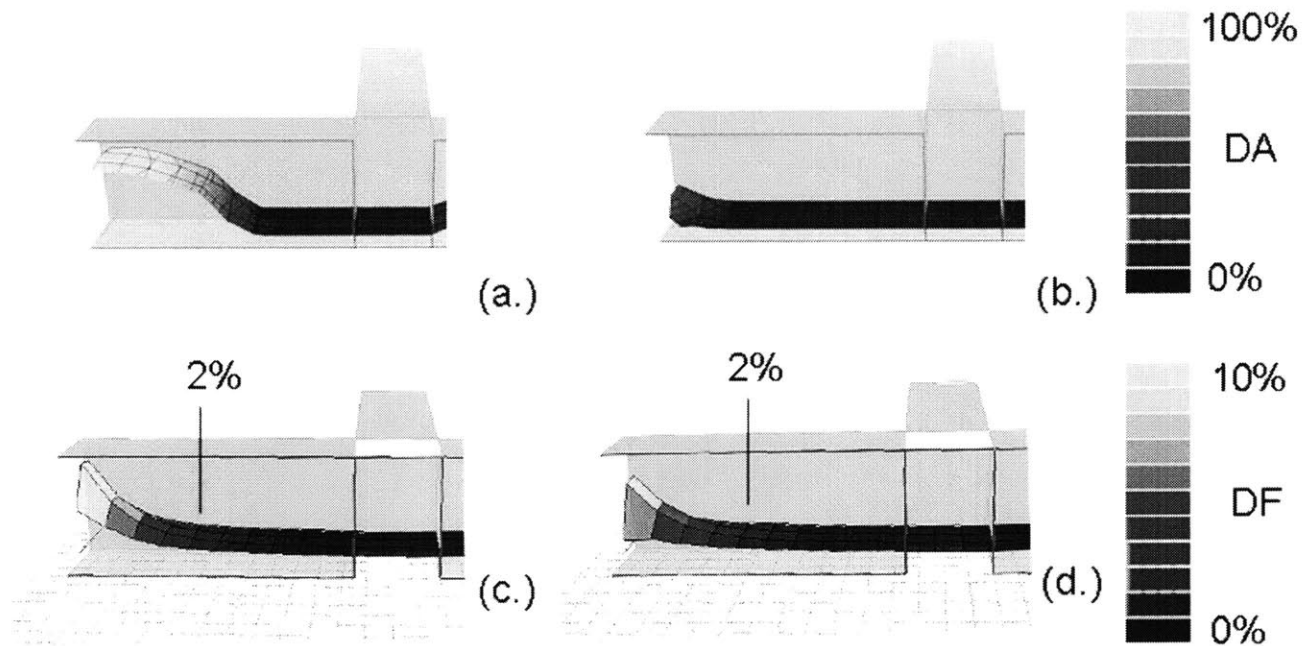


Fig. 20
Sample visual
comparison of north
orientation for 2 façade
types using daylight
autonomy and daylight
factor

Daylight autonomy:

- a. Curtain wall
- b. Punched opening

Daylight factor:

- c. Curtain wall
- d. Punched opening

Note: 2% contour line shows that for the purpose of determining LEED point, both have the same result, even though the curtain wall has much higher levels of autonomy

2.7 Exercise 3: Façade retrofitting options

In the third and most detailed series of simulations, interior and exterior upgrades were modeled to predict how these retrofitting measures might enhance the utilization of daylight. The measures are organized in order of ascending cost and complexity, starting first with upgrades to the interior, and ending with complete retrofit of the façade.

The same typical room was utilized and the same (4 x 9) level of resolution was used as in the previous calculations to generate averaged daylight levels for each spatial zone. Due to the computationally intensive nature of these simulations it would be very difficult to simulate for all the façade types and orientations. Instead the work focused on one façade type (type (a) or curtain wall) in the north and south orientations to provide a range of values that might be involved in a typical retrofitting process. For each of the upgrades outlined below, the electrical power in kWh/ft²/yr for zones 1,2 and 3 was calculated using Daysim. The program calculates this by taking the assumed lighting power density of 16.2 w/m² or (1.5 w/ft²) and reducing this for the time period for which the available daylight illuminance exceeds 500 lux. Since dimming is assumed, power reductions will also occur when available daylight levels are below 500 lux, but can be augmented with

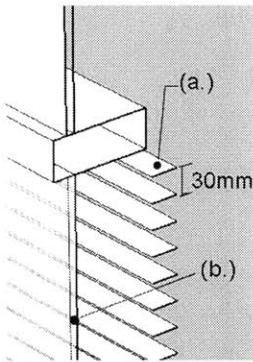


Fig. 22
Existing Blind model
a. flat white finish
b. glass panel



Fig. 21
Interior of building 36
showing how even
light grey ceiling and
floor treatments can
reduce daylight
utilization

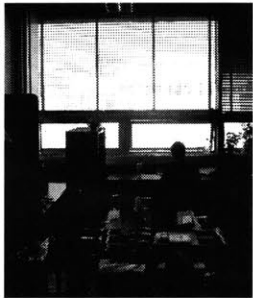


Fig. 23
Existing blinds in
building 26 (site photo
by author)

artificial light. Also, for all of the simulated upgrades, the daylight autonomy is reported as an average for each individual zone in the test room.

The upgrades are compared to a base condition of a single-glazed curtain wall resembling building 26 that was emblematic of the 1950-60s era façades. All base case assumptions, including interior finishes, match the existing conditions of building 26 as much as possible. The walls are 50% reflective as with an off-white paint or walls that are half covered with darker coverings. The ceiling is 80% reflective white acoustic tile ceiling. The floor is 30% reflective vinyl composition tile.¹⁸ The aluminum clad curtain wall system includes single layer glazing with green body tinting, reflective coatings, and an applied solar film. The glass is presumed to have a visual transmittance of 50%.¹⁹

The base case includes several occupant behavior assumptions. Lighting is presumed to be manually switched on or off by the building occupant. An average of (2) user behavior models are assumed. One occupant turns the lights off and on according to ambient lighting conditions, the other does not. The matte white 30 mm metal venetian blinds of building 26 are modeled as flat rectangular polygons. The blinds are assumed to be lowered at all times but are trimmed to the horizontal angle.²⁰ The base assumption for blind usage is an average between two extreme user profiles. One user only places blinds in the vertical position when there is glare, defined as solar irradiation exceeding 50 watts/m². The second type of user keeps the blinds trimmed vertical all day long so that glare is avoided. These assumptions were based on the observation that manually raised blinds of this type tend to stay lowered though some users actively adjust their trim angle throughout the day.

¹⁸ These parameters are close to the ASHRAE 90.1 standard for daylight calculation: 80% for ceilings, 50% for walls, and 20% for floors

¹⁹ A more detailed description of existing glass types can be found in Appendix B

²⁰ The decision to consider the blinds on the north as lowered but open is based on the author's observation that building occupants tend to keep the Venetian blinds lowered. This could be attributed to the difficulty in operating the blinds or settling on a position which satisfies all preferences in an open laboratory or office area.

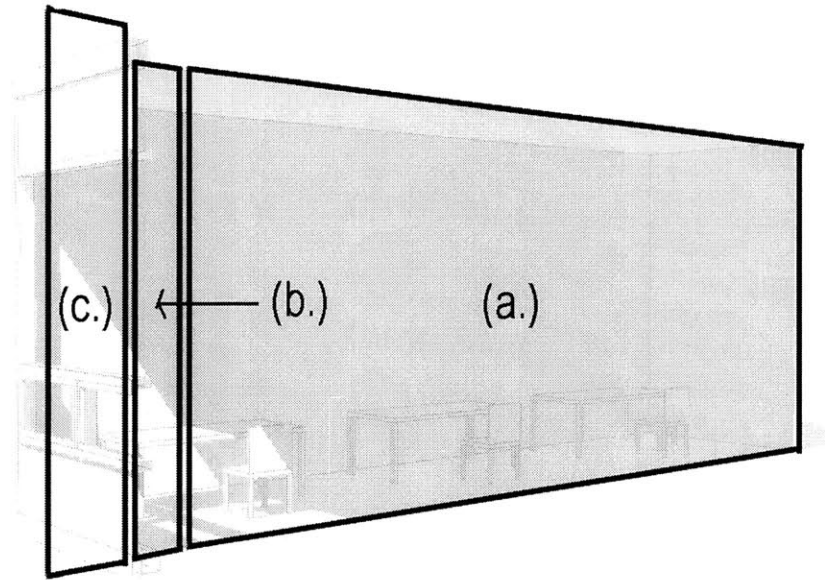


Fig. 24
Different intervention
realms
a. Interior
b. Selective
c. Transformative

Three realms of intervention are assessed in this standard section of workspace and façade.

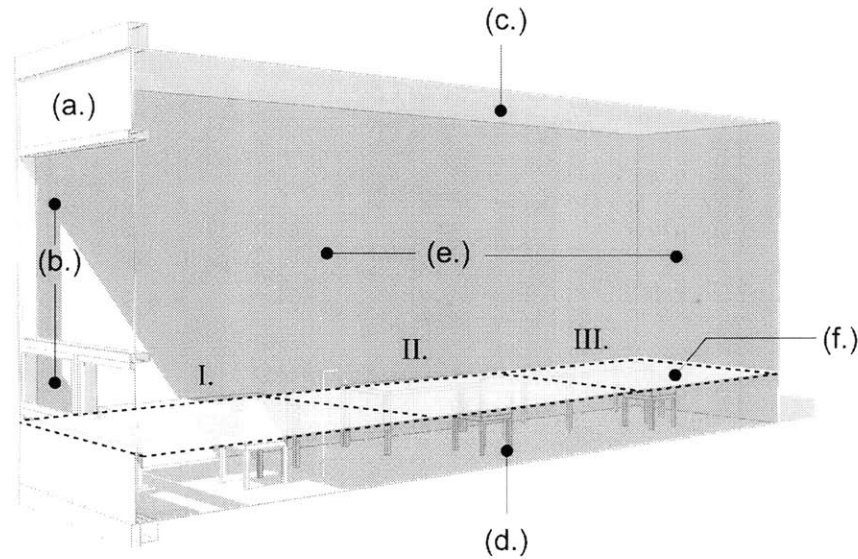
A. Interior

This series of simulations compares the impact on daylight autonomy of measures taken on the interior. The first upgrade increases the reflectance of the primary interior wall surfaces from 50% to 80% (which would result from painting off-white walls white and limiting bulletin boards and other dark surfaces). The second upgrade, advanced ceiling treatments, involves replacing 80% reflective white acoustic tile ceiling with 90% reflective specular ceiling tiles. In the final internal upgrade simulation, the above upgrades are included and all fixture ballasts are replaced with automated dimmable electronic ballasts, each zone individually controlled by a photo sensor. These upgrades are also included in all subsequent upgrade simulations above the base case (in B and C below).

Fig. 25

Test room

- a. Opaque metal curtain wall elements
- b. Tinted glass
- c. Ceiling of 0.8 reflectance
- d. Walls of 0.5 reflectance
- e. Floor of .3 reflectance
- f. Task plane with (3) zones each having (12) illuminance sample points



B. Selective

Selective façade measures involve substituting elements of the façade system. The first simulation substitutes the manual blinds of the base case (with an average of 2 extreme user profiles described above) with automated blinds that respond directly to light levels. Blinds are only in the vertical position when glare is experienced. The second simulation improves the blind system by replacing the standard Venetian blinds with larger, specular blinds that have an upwards facing concave surface that reflects light towards the ceiling whenever there is glare. Improvements to the blinds were simulated, including larger. The third simulation includes the base case assumptions for manual blinds, but changes the darkened heat-absorbing glass with 50% visual transmittance to a glass that is 78% transmissive.²¹ The final simulation of the selective façade measures includes both the automated and improved blind upgrades and the transmissive glass upgrade.

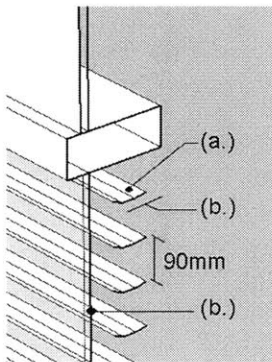


Fig. 26

Advanced redirecting blind model

- a. specular aluminum finish
- b. segmented in model
- c. glass panel

C. Transformative

Transformative façade measures involve major manipulations to the façade itself and are in a separate cost category altogether, as they potentially involve new exterior structural connections, glass and fixing systems. These simulations all assume that the interior upgrades (in A above) and the only transmissive glass upgrades (in B above) have been made. The specular reflective blind upgrades are not included in these simulations.

²¹ 78% is the transmittance of high performance insulated glass units a spectrally selective and low emissivity coating, new glass maintains the roughly same Solar heat gain coefficient while providing higher daylighting performance

The first simulation in this series replaces the top spandrel panel with an additional glazed panel to increase the glazing area. This upgrade is illustrated in Fig 28a. The second retrofitting measure adds a shaped light shelf to the exterior (see Fig 27). Shaped exterior light shelves have been shown to project diffuse light into a space [Kischkoweit-Lopin 2002]. The third simulation adds horizontal fixed louvers to the exterior (See Fig 28b). Horizontal fixed louvers have been shown to decrease the amount of glare. The final simulation includes all three of these transformative façade upgrades.

Fig. 27

Shaped light shelf
model

- a) Segmented
reflector mirror
finish
- b) single layer of
protective glass
- c) interior reflectors
- d) interior light shelf
also mirror finish

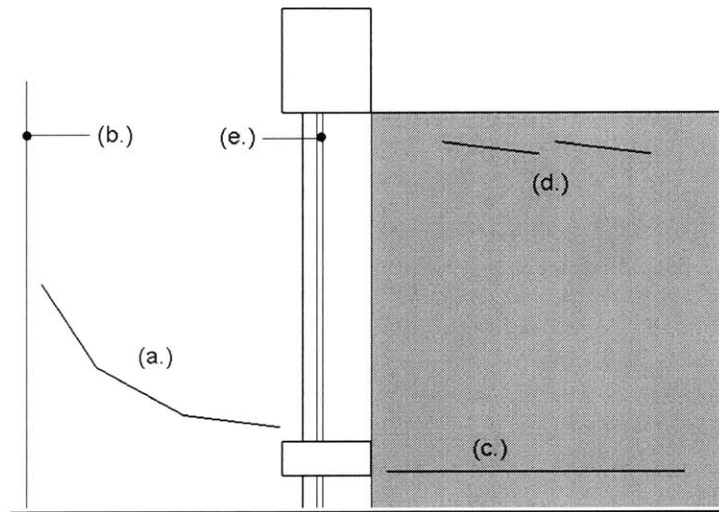


Fig. 28

Glazing area increase and fixed louvres

- a) Spandrel panel replaced with glass
- b) Fixed louvers added to exterior Aluminum

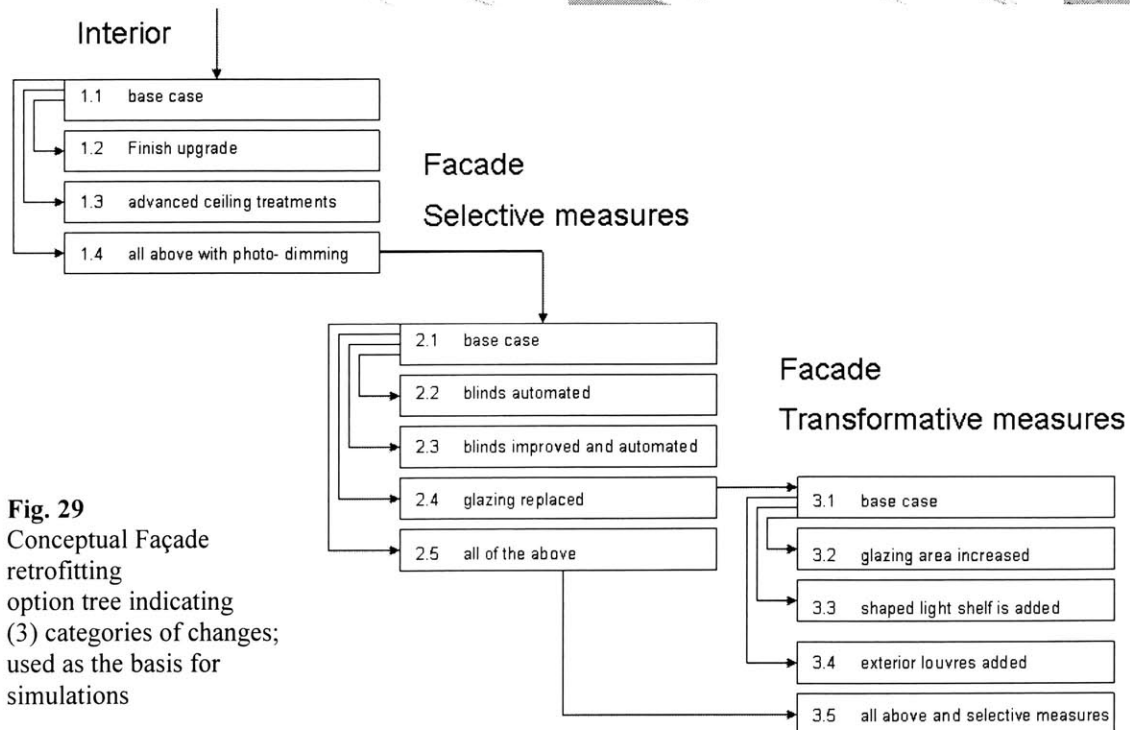
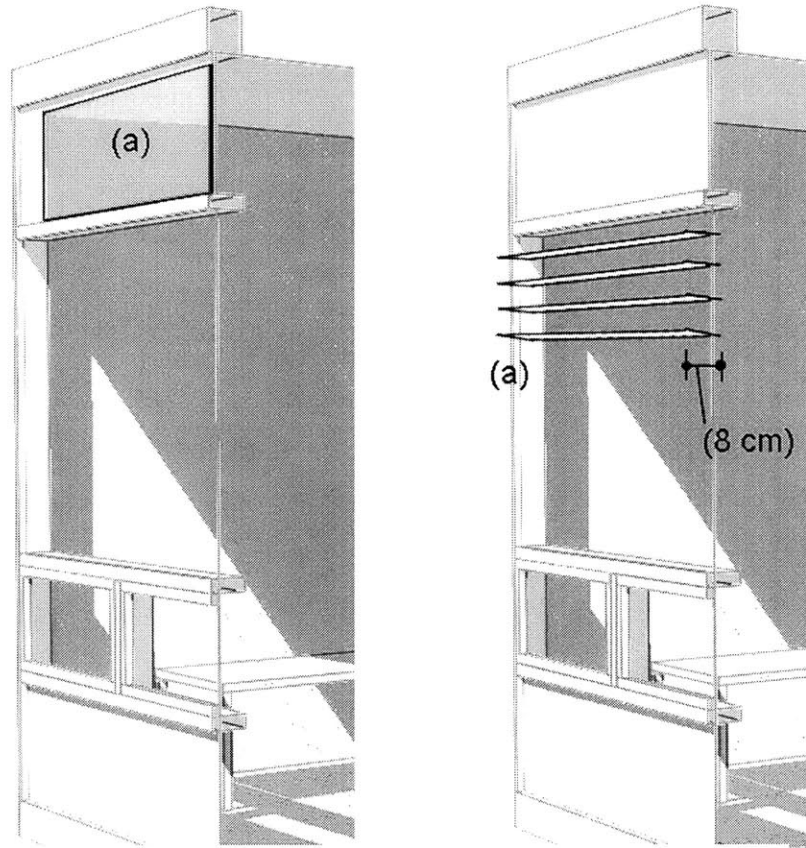


Fig. 29

Conceptual Façade retrofitting option tree indicating (3) categories of changes; used as the basis for simulations

D. Cost and Energy

The cost of each measure was estimated in US dollars per unit of façade area. A unit of façade is considered to be the area corresponding to the test room of approximately 26 m² (280 square feet). The estimation of interior measures assumed that upgrades would be made to the interior surfaces and electrical components corresponding to that façade unit. Costs were determined on acceptable standard prices for materials and labor [RS MEANS 2005]. In the interior measures, it is assumed that the interior retains its current luminaries, ceiling layout, and a control package is added to each fixture. The cost of the electronic ballast and photo-sensor package assumes both can be installed without replacing the luminaries or making additional home runs to the electrical panel. The costs of automatic blinds were estimated with information provided by a report by a daylighting consultancy Bartenbach Licht-labor [BL 2005].

The transformations to the façade were estimated with input from a Providence, R.I. construction firm and include the cost of attaching structural elements to the existing structure, and/or adding a second layer of glass as part of a shaped light shelf system.

This calculation does not account for inflation, the rise in electrical prices, thermal energy savings, or decreased future maintenance costs. This work is only an approximation and is not meant to be an economic overview of façade renewal.

It is useful compare the energy saving effect of daylighting measures to an estimate for the energy required to heat and cool a similar office room. These rough calculations were made with the web-based tool MIT design advisor [D]. These calculations are intended to provide context for the daylight enhancement measures.

3.0 Results

3.1 Exercise 1: Urban light access

This exercise simulates how shading from other nearby buildings affects daylight autonomy. Table 2 lists the calculated daylight autonomy for the test rooms at 10 locations (letters (a)-(j) specified on the MIT campus map in Table 2 above) in different orientations and extremes of exposure and shade. Note that the daylight autonomy levels in this simulation are higher than in subsequent simulations, because for the purposes of focusing on obstruction and orientation, glass is assumed to have 100% transmittance.

Unobstructed		Zone 1	Zone 2	Zone 3
a.	# 54 South high	92	87	89
b.	# 54 North high	93	89	89
c.	#16 South high	86	77	80
Slightly Obstructed				
d.	#36 South high	87	74	57
e.	#36 North high	86	68	42
f.	#26 West high	85	70	54
g.	#26 East high	83	65	50
Highly Obstructed				
h.	#26 East low	83	59	16
i.	#36 North low	86	68	42
j.	#36 South low	86	68	41

Table 2:
Summary of daylight autonomy taken at the (3) zones at a sample set of locations

From the results of this simple simulation, which does not account for glare and assumes perfect glass visual transmittance, it appears that obstruction is a far more determinant of daylight autonomy than orientation. The façades with unobstructed north or south orientations (a, b and c) have the highest daylight autonomy levels deep into zones 2 and 3. There is negligible difference amongst the north and south orientations for daylight autonomy in these unobstructed views.²²

²² The issue of glare is not addressed in this simulation. If glare were taken into account, it is likely that orientation would have an impact on daylight autonomy in the unobstructed locations.

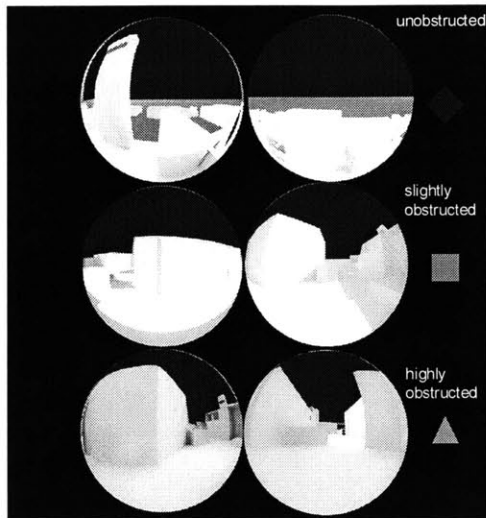


Fig 29a:
Visualizations of three levels of obstructions. 180 degree hemispherical lens projection were created with radiance

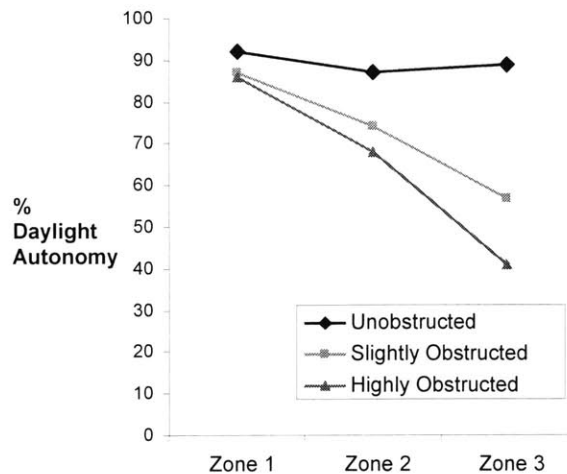
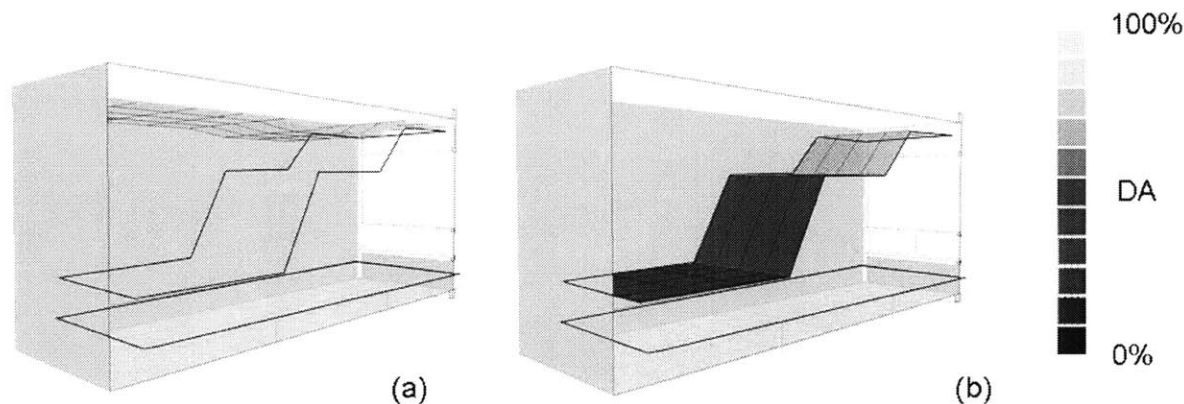


Fig 29b:
Summary of daylight autonomy taken at three levels of obstruction on the southern orientation.

The slightly and highly obstructed locations still have a good deal of autonomy in zone 1, but the levels drop off sharply in zones 2 and 3. In the highly obstructed east-facing test room (h), daylight autonomy drops precipitously from 83 in zone 1 to 16 in zone 3, whereas the other orientations only drop to 41 and 42. The degree of obstruction is greater in room (h), which likely accounts for this difference (See Figure 18). In the slightly obstructed test rooms, the decline in autonomy across zones is fairly consistent between the different orientations.

Figure 30 plots the autonomy of the two extreme test rooms, the east-facing highly obstructed view (h) and the south-facing unobstructed view (a) and using Ecotect software. Whereas the highly-obstructed room has a rapid decrease in daylight autonomy across the space, the unobstructed south-facing room maintains a high daylight autonomy through the depth of the room.

Fig. 30
Summary of daylight autonomy in zones 1-3
(a) an unobstructed area room (a)
(b) an un obstructed area (h)



3.2 Façade typology

This simulation assesses the contribution of façade type to daylight autonomy. The four prevalent façade typologies were modeled in all four orientations to calculate an average daylight autonomy for each façade. The results are listed in Table 3.

Table. 3
Summary of
calculated daylight
autonomy and
daylight factor by
façade type,
averaged across
depth of test room
and the (4)
orientations

Façade Type	Daylight Autonomy
a. Curtain wall	49.9
b. Punched opening	28.7
c. Flush frame and in-fill	46.9
d. External frame and in-fill	36

The curtain wall (a) and flush frame and in-fill (c) façades have the highest levels of autonomy in the above calculations. Note that the curtain wall daylight autonomy levels are higher even though the glass area to opaque wall area is in fact larger for the two concrete frame types (c and d). In part this might be due to the flush nature of the glazed portion for the curtain wall (the curtain wall has no overhang), and the absence of dark vertical mullions at 1'6" spacing.

Figure 31 and 32 plots the north and south daylight autonomy levels for each of the façade typologies. The curtain wall (a) has the most favorable daylight autonomy distribution in both orientations. The punched opening (b) has the advantage of integral shading on the south, but this shading causes dramatically reduced daylight autonomy in the northern orientation. The concrete frame types (c and d) have fairly similar autonomy patterns across the test room, although the flushed frame and in-fill (c) has improved light penetration on southern exposure.

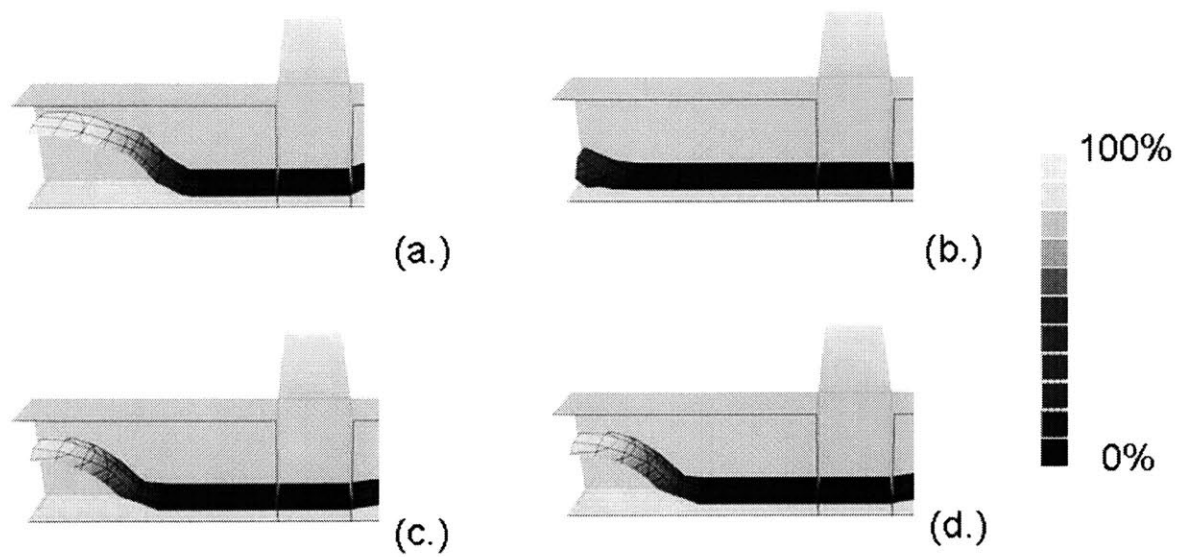


Fig. 31
Daylight autonomy levels for the 4 facades types facing **north**
a. Curtain wall
b. Punched opening
c. Flush frame and in-fill
d. External frame and in-fill

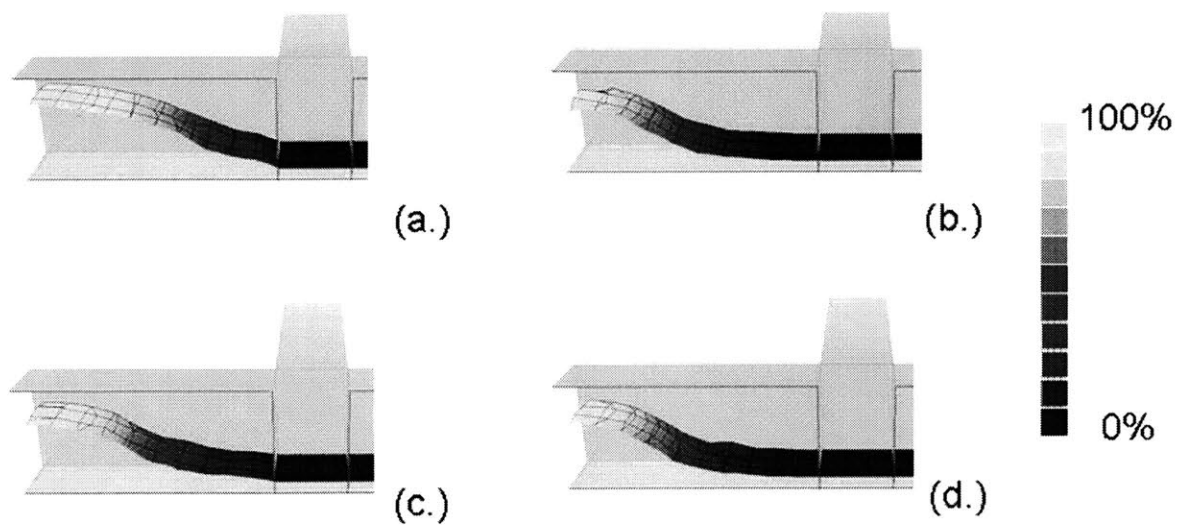


Fig. 32
Daylight autonomy values for the 4 facade types facing **south**
a. Curtain wall
b. Punched opening
c. Flush frame and in-fill
d. External frame and in-fill

To compare how daylight autonomy is a more sensitive measure of lighting levels in the interior compared to daylight factor values, Reference Figure 20 in methodology, which compares daylight autonomy and daylight factor.

3.3 Exercise 3: Daylight enhancing measures

This third, more comprehensive exercise simulates the impact of interior and exterior upgrades to daylight autonomy on a standardized curtain wall façade type in the north and south orientations.

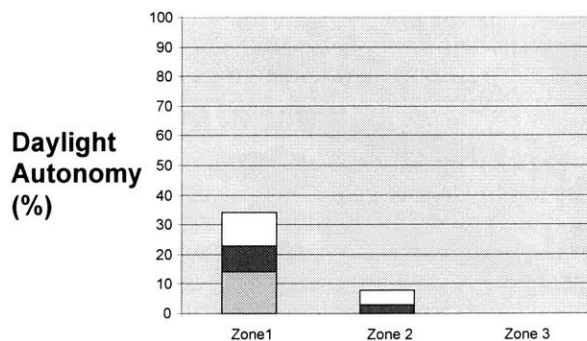
Table 4: Impact of internal upgrades on electrical power density and daylight autonomy

A. Interior Results

The first series of simulations tests changes to the interior: adding finish upgrades, ceiling treatments, and photo-dimmers, as described in detail in the methodology section above. The results are listed in Table 4 below.

Upgrade	Electrical Power Density (kWh/ft ² /yr)		% Decrease in Electrical Power from Base Case		Zone 1 Daylight Autonomy (%)		Zone 2 Daylight Autonomy (%)		Zone 3 Daylight Autonomy (%)	
	North	South	North	South	North	South	North	South	North	South
Base case	3.2	3.1	-	-	14	33	0	14	0	1
Finish upgrade	3	3.0	6%	3%	23	37	3	21	0	5
Ceiling treatments	3	2.9	6%	7%	25	38	5	24	0	7
All of the above with photo dimming	2.9	2.8	9%	10%	25	38	5	24	0	7

(a) Northern Orientation



(b) Southern Orientation

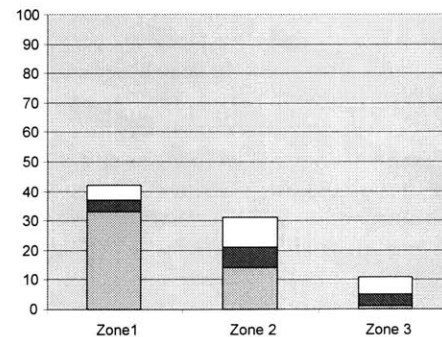
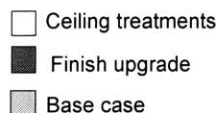


Table 4 ab: Impact of individual interior measures on daylight autonomy, a comparison of orientations.



The above simulations illustrate that these interior renovations combined may save up to 10% of electrical power and increase daylight autonomy levels by 5 to 10 percentage points in zones 1 and 2. The base case has no daylight autonomy in zone 3 north due to the low overall sky luminance and low transmittance of the glass. In general these interior renovations are of only marginal benefit to zone 3 in the southern orientation only, with no impact in the northern orientation. The finish upgrade, which increases the reflectance of the primary interior surfaces from 50 to 80%, results in a 3 to 6% decrease in electrical power. The ceiling treatments, which increase reflectance to 90%, result in a similar benefit (6-7% decrease in electrical power). Adding these measures and automated photo-dimming to the base case results in an additional 3 percentage point decrease in electrical power in both orientations.

B. Selective Results

Table 5: Impact of selective upgrades on electrical power density and daylight autonomy

This series of simulations involves substituting elements of the façade system, upgrading to automated blinds, substituting automated blinds with a concave shape to allow upward light reflection, and replacement of glass to increase the transmittance from 50 to 78%, as described above in Methodology. These simulations (except the base case) all include the three upgrades (finish, ceiling and photo-dimming) of the prior simulation series. The results are summarized in Table 5 below.

Upgrade	Electrical Power Density (kWh/ft ² /yr)		% Decrease in Power from Base Case		Zone 1 Daylight Autonomy (%)		Zone 2 Daylight Autonomy (%)		Zone 3 Daylight Autonomy (%)	
	North	South	North	South	North	South	North	South	North	South
Base case	3.2	3.1			14	33	0	14	0	1
All 3 interior upgrades (in A)	2.9	2.8	9%	10%	25	38	5	24	0	7
Blinds automated	2.7	2.3	16%	26%	51	58	9	37	0	11
Blinds improved and automated	2.1	2.0	30%	33%	62	70	22	48	0	14
Glazing replaced	2.6	2.6	19%	19%	34	43	18	25	0	5
All of the above	1.8	1.2	44%	61%	76	80	52	70	4	44

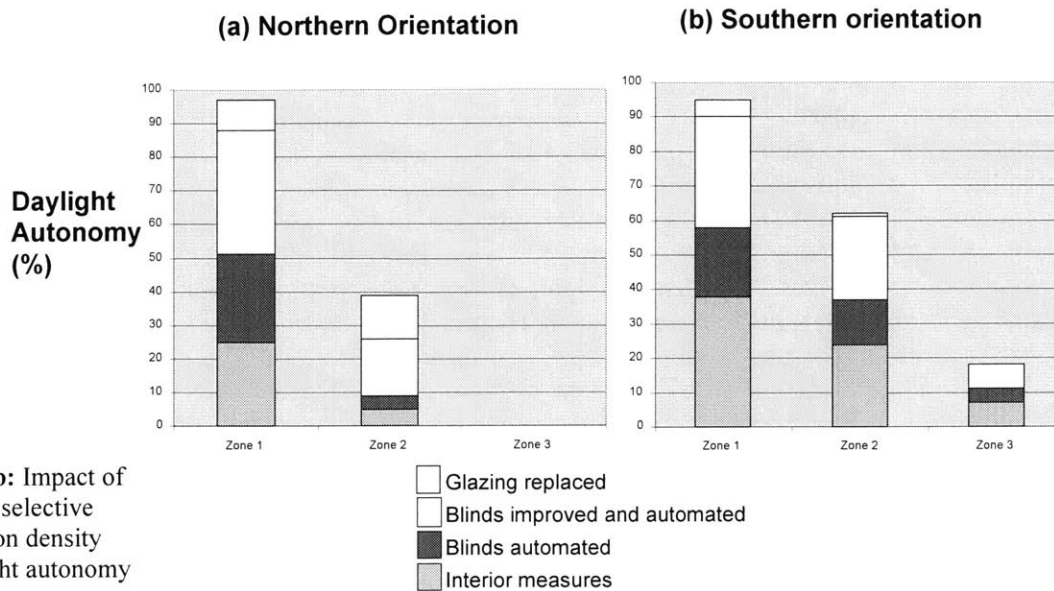


Table 5 ab: Impact of individual selective measures on density and daylight autonomy

This series of simulations results in more substantial power savings and improvements in daylight autonomy than the interior measures. Automated blinds result in a 6-7% electrical power savings on top of the interior changes alone. Daylight autonomy improves substantially in both orientations with the addition of automated blinds, although the improvement is larger in the southern orientation, extending into zone 2. The benefit of automated blinds may be greater in the southern orientation because of the effectiveness of these blinds at stopping glare at the task plane only when it is present. Glare is not an issue in northern orientations. The improved specular reflective blinds results in an impressive 14 and 7 percentage point additional power savings in the northern and southern orientations, respectively. The benefit of these blinds is likely greatest in the north, where daylight levels are lower, because of the ability of these specular blinds to redirect diffuse light into zones 2 and 3.

The replaced glazing simulation includes the base case assumptions for manual blinds, but increases glass transmittance from 50% to 78%. The addition of this upgrade saves electrical energy and improves daylight autonomy in both orientations, but the effect is not as great as that of automating blinds, particularly in the southern orientation. The combined simulation of automated and reflective blinds with the higher transmittance glass results in a substantial electrical savings (35% northern, 51% southern orientation) compared to the case involving interior upgrades only. Daylight autonomy improves to 44% in the southern orientation in zone 3, although the northern orientation still requires artificial lighting in zone 3 with these additions. Overall, selective measures are of greater benefit to façades with a southern orientation.

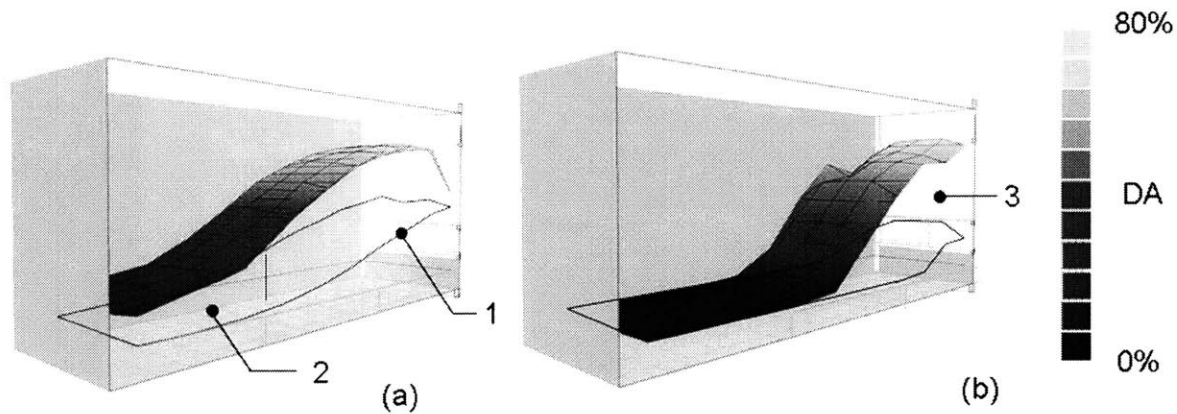


Fig. 33
Graphic comparison of the retrofitting with automated blinds on
a. south orientation b. north orientation

Notes:

1. outline of contour graph of base case indicated showing benefit in zone 1 and 2
2. Zone 3 improvement apparent on southern orientation, (northern orientation stays flat in zone 3)
3. Zone 1 improvement in northern orientation drops sharply in zone II

C. Transformative Results

Table 6: Impact of transformative upgrades on electrical power density and daylight autonomy

The transformative simulations model the impact of increased glazing area through the addition of a glazed panel, a shaped exterior light shelf, and horizontal fixed louvers. The interior upgrades and the high transmittance glazing upgrade are included in all simulations except the base case. Blind upgrades are not included in these simulations. The results are summarized in Table 6 below.

Upgrade	Electrical Power Density (kWh/ft ² /yr)		% Decrease in Power from Base Case		Zone 1 Daylight Autonomy (%)		Zone 2 Daylight Autonomy (%)		Zone 3 Daylight Autonomy (%)	
	North	South	North	South	North	South	North	South	North	South
Base case	3.2	3.1			14	33	0	14	0	1
Interior upgrades (A) + replaced glazing (B)	2.6	2.6	19%	19%	34	43	18	25	0	5
Glazing area increased	2.1	1.7	34%	45%	47	59	29	39	5	11
Shaped light shelf added	1.4	1.2	56%	61%	78	65	61	52	25	28
Exterior louvers added	2.7	1.2	16%*	61%		69		54		29

* a savings is lower than the interior measures is possible if the element reduces transmission

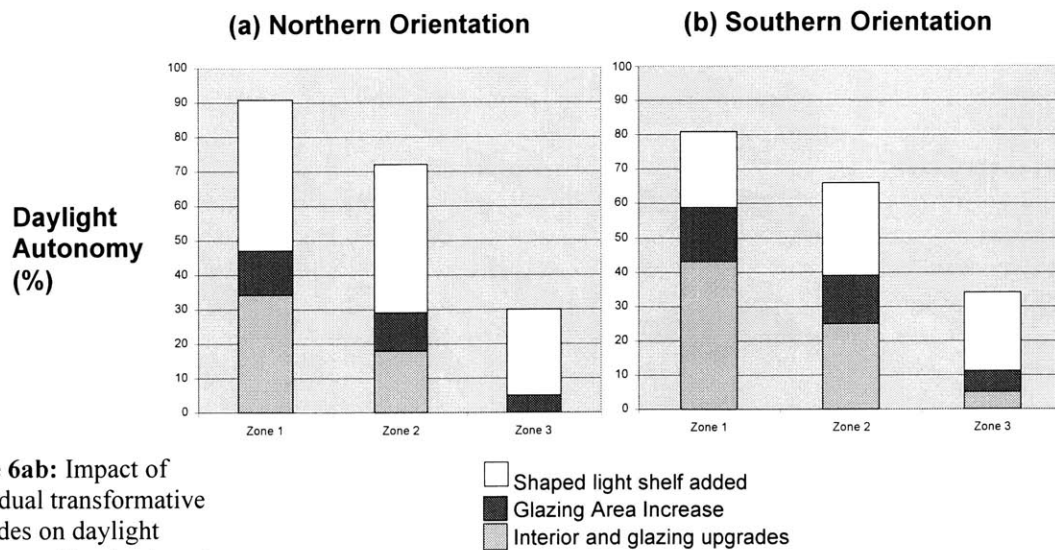


Table 6ab: Impact of individual transformative upgrades on daylight autonomy. Fixed external shades are not included.

These more extensive upgrades result in substantial improvements in power requirements and daylight autonomy. The increased glazing area from the replacement of the top spandrel panel with an additional glazed panel results in an additional 15% power savings in the northern orientation. Daylight autonomy levels improve to 29 and 39% in zone 2 in the northern and southern orientations, respectively. The addition of the shaped exterior light shelf, which projects diffuse light into the interior, improves daylight autonomy to 28% in zone 3 in the southern orientation. It is also one of the few upgrades with a substantial power savings in the northern orientation. The addition of an exterior louvre has significant electrical power density and daylight autonomy improvements in the southern orientation. In the north it actually worsens energy requirements compared to the interior upgrades and improved glazing alone, because the louvers block available light and, unlike in the southern orientation, do not protect from glare.

On the northern orientation, transformative changes to the façade, particularly the enlarged glazing area and shaped exterior light shelf, have a greater energy and daylight autonomy benefit compared with advanced blinds and glazing transmittance (Table 34a versus Table 34b). On the southern orientation, the gains from automated and reflective blinds and improved glass transmittance are similar in magnitude to the benefits from the more expensive transformative upgrades.

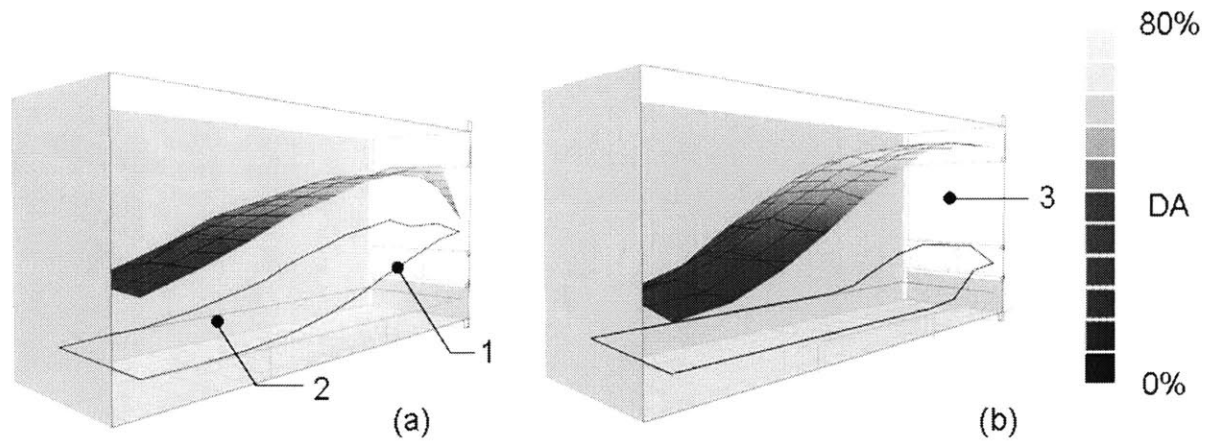


Fig. 34

Comparison of the daylight autonomy due to a retrofitting with shaped light shelf
a. south orientation b. north orientation

Notes:

1. contour of base case indicates improvement in all three zones.
2. largest improvement for zone three (1% to 28%)
3. Northern orientation has steeper fall off but improvement still reaches zone 3

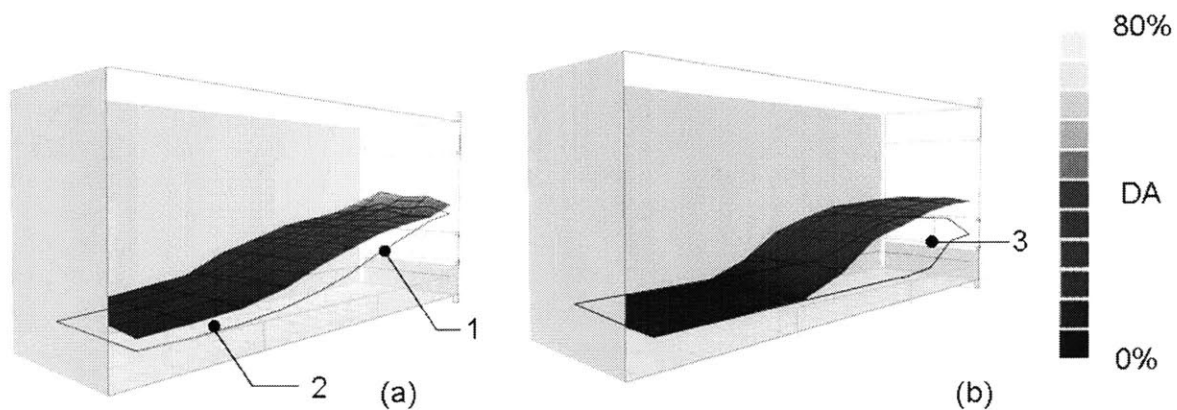


Fig. 35

Comparison of the daylight autonomy due to a retrofitting of the glass

a. south orientation

b. north orientation

Notes:

1. On south, the improvement is spread out over all three zones and is small (15% to 30%)
2. Improvement deeper in space on south
3. On north the improvement is larger but is restricted to Zone 1 and 2.

D. Cost and Energy

Lastly, the estimated energy savings for each of the upgrade scenarios is shown in the graphs below. The results are listed in Table 7.

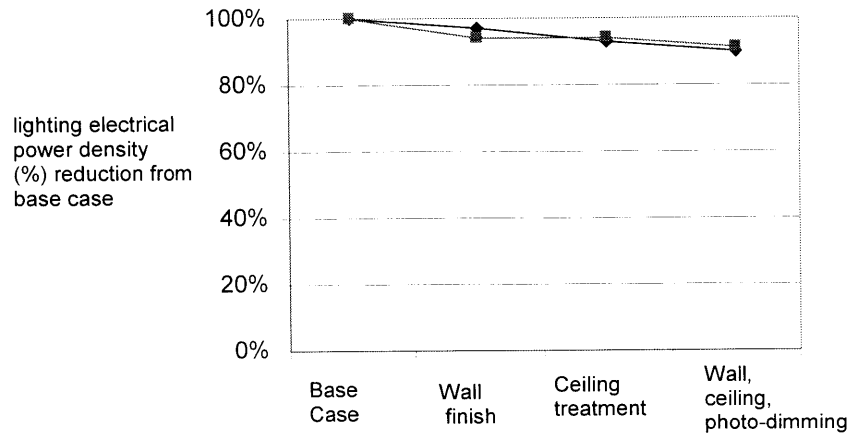


Fig. 36
Reduction in Electrical power as a result of interior, selective, and transformative approaches

Southern orientation is compared to northern orientation,

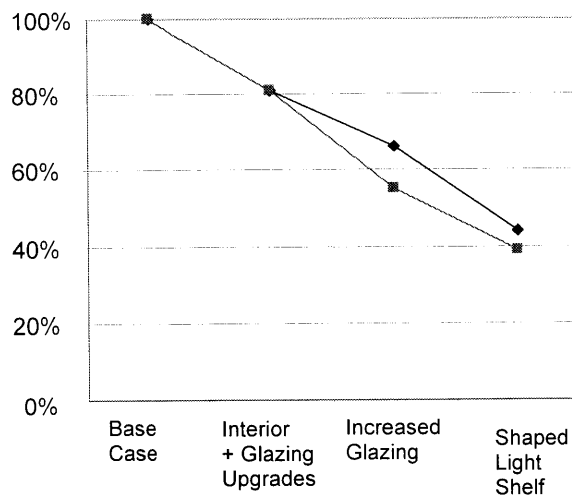
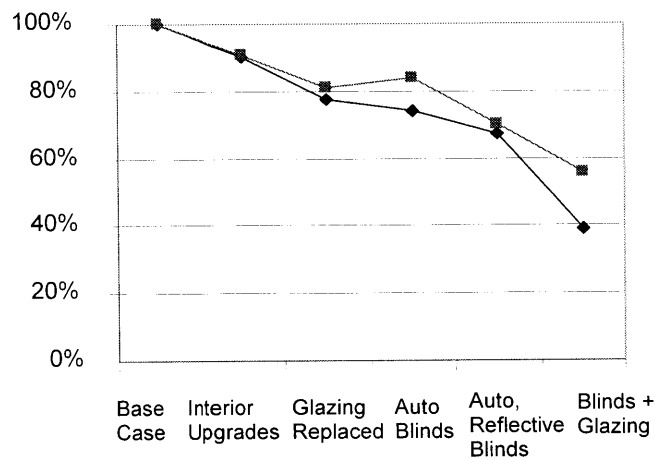
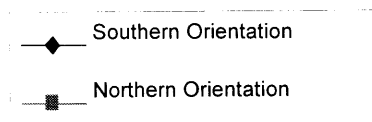


Table. 7
Summary of
electrical energy
savings as
compared to first
cost (USD)

Upgrade	First Cost of Upgrade USD/Façade Unit	Reduction of yearly lighting electrical power consumption (%)	
		North	South
A. Interior			
Finish upgrade	\$500	6%	3%
Ceiling treatments	810	6%	7%
All interior upgrades (Finish + Ceiling + Photodimming)	1,617	9%	10%
B. Selective			
Blinds automated + interior upgrades	2,017	16%	26%
Blinds improved and automated + interior upgrades	2,090	30%	33%
Replaced glazing + interior upgrades	2,483	19%	19%
All interior + all selective upgrades (blinds improved, automated + glazing)	2,956	44%	61%
C. Transformative			
Glazing area increase + replaced glazing + interior upgrades	2,883	34%	45%
Shaped light shelf + replaced glazing + interior upgrades	13,683	56%	61%
Exterior louvre + replaced glazing + interior upgrades	5,883	16%	61%

In addition to the daylight benefits there are significant thermal implications in the selective and transformative strategies. While a detailed study of these effects is beyond the scope of this work, it is worthwhile to indicate roughly how these considerations might affect the decision making process. For the purpose of comparison the units have been reported in KWh/ year.

Table. 8
Estimated energy
requirements for
base case

Energy requirement		North (kWh/year)	South (kwh/year)
Electrical Lighting		864	837
Heating ²³		4213	3335
Cooling ²⁴		836	1140

²³ HVAC system is assumed to be a pure mechanical system providing 1.4 air changes per hour, the system efficiency is 100%,

²⁴ Mechanical cooling is assumed with well mixed air circulation. Chiller C.O.P = 3.0

Upgrade	Heating energy savings % from base case (or penalty %)		Cooling energy Savings % from base case (or penalty %)	
	North	South	North	South
A. Interior				
Finish upgrade	-	-	-	-
Ceiling treatments	-	-	-	-
All interior upgrades (Finish + Ceiling + photodimming)	-			
B. Selective	-	-	-	-
Blinds automated + interior upgrades	(2%)	(12%)	6%	11%
Blinds improved and automated + interior upgrades	(1%)	(12%)	5%	7%
Replaced glazing + interior upgrades	19%	21%	8%	15%
All interior + all selective upgrades (blinds improved, automated + glazing)	18%	11%	11%	18%
C. Transformative				
Glazing area increase + replaced glazing + interior upgrades	23%	32%	(23%)	(23%)
Shaped light shelf + replaced glazing + interior upgrades	22%	31%	28%	28%
Exterior louvre + replaced glazing + interior upgrades	-	-	-	-

Table. 9
estimated thermal
energy savings or
penalties for all
upgrades

3.4 Limitations of simulation

There are many limitations to this type of simulation that are worth mentioning here. The one hour time step utilized throughout the simulation process enables shorter simulation times and generally facilitates the simulation of multiple retrofit scenarios. However, a shorter time step would be more accurate. The blind usage assumptions do not account for users raising the blinds; rather it is assumed that blinds are kept down and trimmed open when appropriate. Another concern with this simulation process is the manner in which the issues of urban daylight access, façade type, and retrofit type are separated, in favor of reducing the amount of simulations required. All of these factors contribute to daylight autonomy. The most accurate simulation would take all of these variables into account simultaneously. The complexity

of simulations was limited by the time required to complete computations (the most involved façade retrofit scenarios took roughly 48 hours to generate solutions on a dual- Pentium 4 processor) and the time required by translating various outputs from one software package to another.

The report on the thermal implications of these changes is very limited. In the cases where glass was substituted, an effort was made to maintain the same level of protection from solar heat gain by utilizing spectrally selective glass. There are other questions concerning solar gains, which, may occasionally be useful in offsetting heating energy. These cases are not addressed in these simulations. In general, the replacement of the glass is a key determinant of thermal performance. The increase in glazed area is a significant issue on the southern exposure, but also shows how integrating shading and daylight enhancements, with measures such as the light shelf, offers a balanced solution.

4.0 Conclusions

4.1 Urban Light Access

Although the simulation of urban light access for 10 locations with different orientations and levels of obstruction is highly simplified, it illustrates that the level of obstruction essentially trumps any effect of orientation on daylight autonomy. More complex simulations in this paper illustrate that orientation is indeed a very important determinant of daylight autonomy. However, this analysis demonstrates that these effects are minimal compared to the effect of a major change in the level of obstruction. This is an important point for large institutions like MIT managing both façade renovations in aging buildings and new construction on the same campus. Expensive façade renovations intended to improve daylight autonomy in an aging building should not be pursued if a major decrease in the level of obstruction may occur.

4.2 Façade Typology

The simulation comparing the daylight autonomy of four common aging façade types demonstrates that the curtain wall and the flush frame and in-fill façades have significantly better levels of daylight autonomy than punched opening and external frame and in-fill façades. The punched opening façade, in particular, has poor daylight autonomy in the northern orientation, due to the integral shading in the window profile. This analysis also demonstrates how poorly the daylight factor, as a metric, distinguishes between the interior lighting levels of different façade solutions. The two extreme examples—the curtain wall façade with an averaged daylight autonomy of 49.9, and the punched opening, with an averaged daylight autonomy of 28.7—have comparable daylight factor levels (fig 20).

Of all of the façade types the curtain wall (Fig 19a) and the flush frame and in-fill (Fig19c) have the most potential for transformation. The curtain wall presents the special opportunity to open the spandrel and divide the function of the window. The same is possible in the frame and in-fill. The punched openings in pre-cast concrete panels are limited in their capacity to be transformed for northerly and obstructed façades due to reduced access to sky area. The external concrete frame has the same limitations due to the large overhang.

4.3 Façade retrofitting options

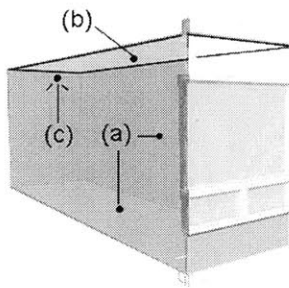


Fig. 37
simulation model showing
interior measures:
a. wall and floor finishes
b. ceiling
c. photosensor

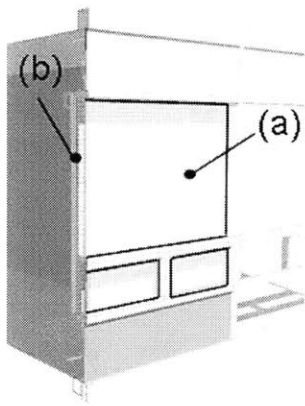


Fig. 38 selective façade
changes
a. glass replacement
b. blind upgrades

The first level of upgrades in the simulation of upgrades to a standard curtain wall façade illustrates that simple and inexpensive renovations to a building's interior can result in significant energy savings and modest gains in daylight autonomy. The estimated cost of upgrading wall finish, ceiling reflectivity and adding photo-dimmers is only \$1617 per façade unit and results in an estimated 10% electrical energy savings with some improvement in daylight autonomy in zones 1 and 2. Historically there has been a trade off between the savings potential of occupancy sensors and the risk that they are rejected by building occupants. The newest control technology seeks to localize light sensing and control responsibility at the fixture itself. The core of these technologies is the ability to address each fixture individually.

The selective upgrades to the façade result in impressive gains in electrical savings and daylight autonomy in both southern and northern orientations. These gains are generally greater in the southern orientation. The addition of automated blinds alone is an inexpensive intervention (only an additional \$400 per façade unit) that reduces electrical power density by 16% in the southern orientation. Daylight autonomy improves by more than 30 percentage points in zone 1 in this orientation with the addition of automated blinds alone. An inexpensive upgrade to improved *and* automated blinds (that are concave and have the capacity to redirect diffuse light deep into a room) results in additional power savings and improved daylight autonomy levels. Finally, replacing 50% transmissive glass with glass that is 78% transmissive costs an additional \$400 per façade unit, but improves energy savings and daylight autonomy to a similar level as the blind upgrades. Taken together, these three relatively inexpensive façade upgrades can result in a substantial improvement in energy requirements and daylight autonomy in both northern and southern orientations. In replacing the glass, the designer also assumes significant thermal improvement. It is important, however that daylighting value of high visual transmittance glass be sought in combination with solar protections such as spectrally selective glass (as has been assumed in the simulations) and automated blinds.

Transformative measures to the façade exterior are more expensive, but also result in marked improvements in daylight autonomy on a similar scale as the selective improvements. However, in the simulations these upgrades, specifically the light shelf and increasing glazing area, result in the most impressive gains in the northern orientation. For the south facing orientation, the benefit of a selective approach and a transformative approach seems to be about equal.

4.4 Identifying retrofit opportunities at MIT

This section considers how a large institution like MIT might apply the above simulations to make renovation decisions. Large institutions often have to prioritize renovation work between many aging buildings in need of repair. Before engaging on complex daylight autonomy calculations for large numbers of buildings and scenarios, it is important to recognize that the depth of space beyond each façade is a major determinant of the potential for renovations to improve daylight autonomy. A façade adjacent to a 3m wide office (with a depth of only 1 zone in the simulations above) is probably not worth renovating towards maximizing daylight autonomy, whereas a façade with space of 3 zones or more in depth behind it is highly suitable. As an example, Figure 38a of north-facing façades in the case study illustrates that some façades surround a space that is 3+ zones deep, whereas others only have a depth of 0-1 zones.

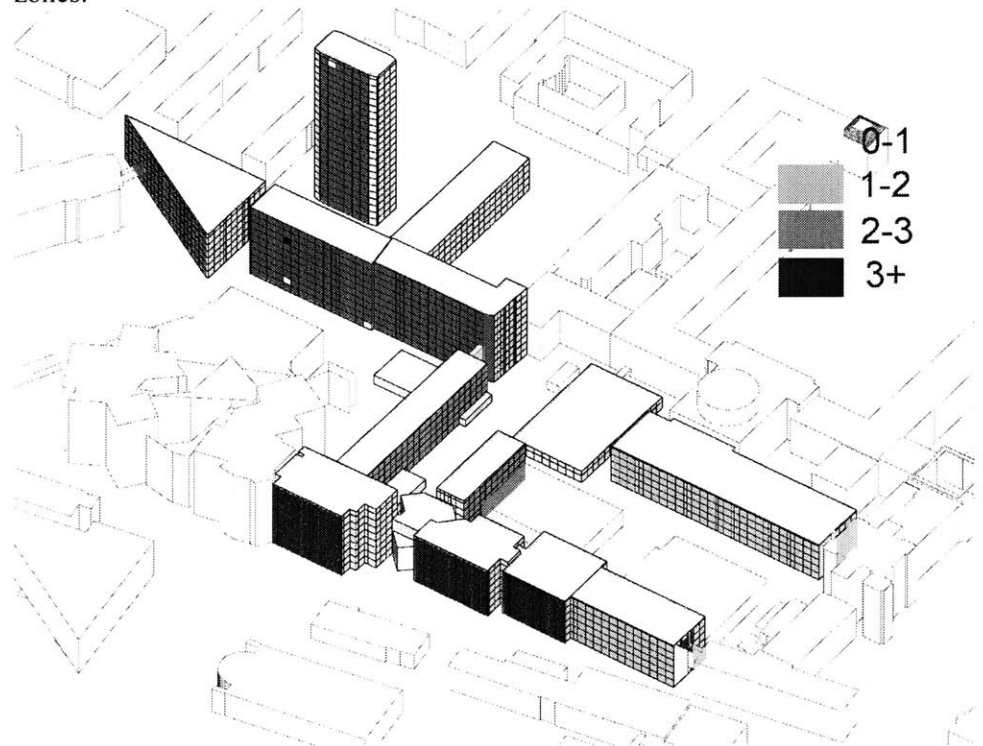


Figure 39:
Space depths
Looking south

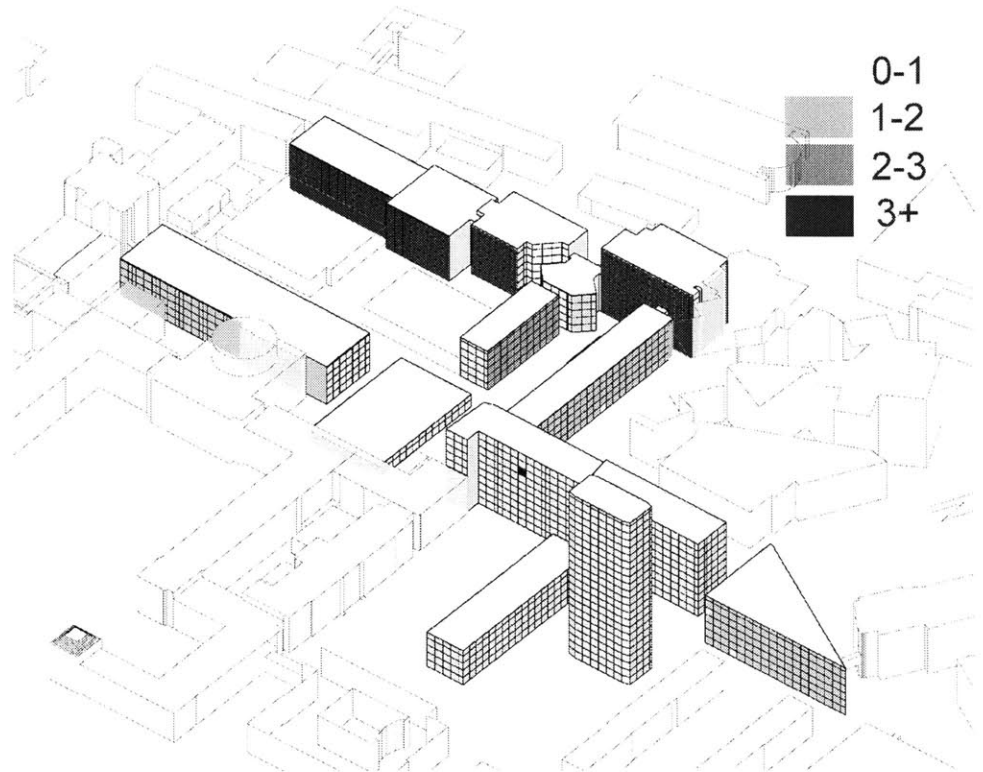


Figure 40:
Space depth
Looking north

As indicated in (Figs 38a) approximately half of the northern-facing façade area has more than 3 spatial zones beyond the façade. In general, more involved retrofits improving the utilization of daylight should first be considered on these façades.

Figure 39 identifies 3 façades, a north-facing curtain wall (a), a west-facing curtain wall (b) and a south-facing concrete frame and in-fill façade (c). The façade typology analyses found that the curtain wall and concrete frame and in-fill façades had similar daylight autonomy values, so the calculations for the curtain wall façade can be applied. Similarly, northern orientations can be presumed to have similar daylight autonomy values for planning purposes. Table 8 applies the annual electrical savings for the entire interior, selective and transformative renovations for the surface area of each façade.

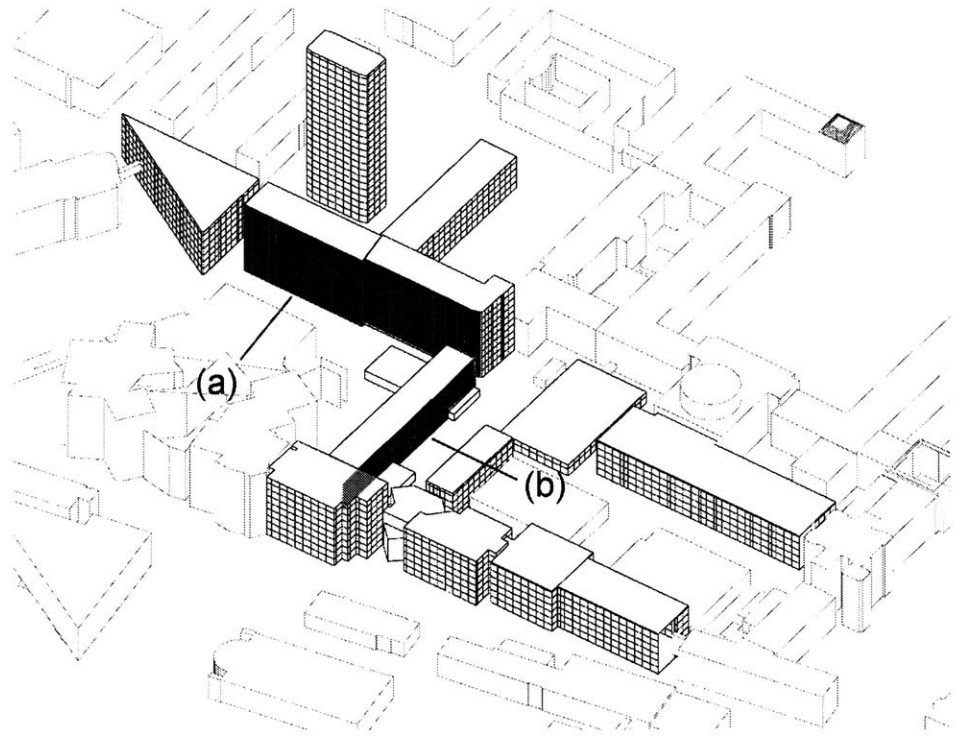


Figure 41:
a. north facades of
buildings 16-56
b. west facades of
building26

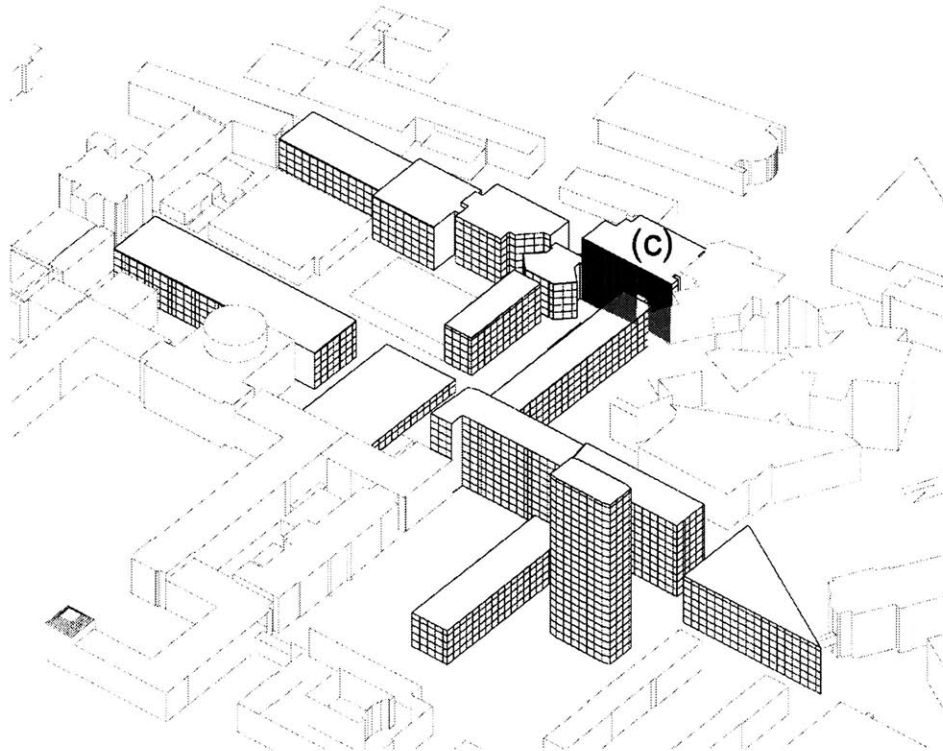


Fig. 42
c. south façade
of building 36

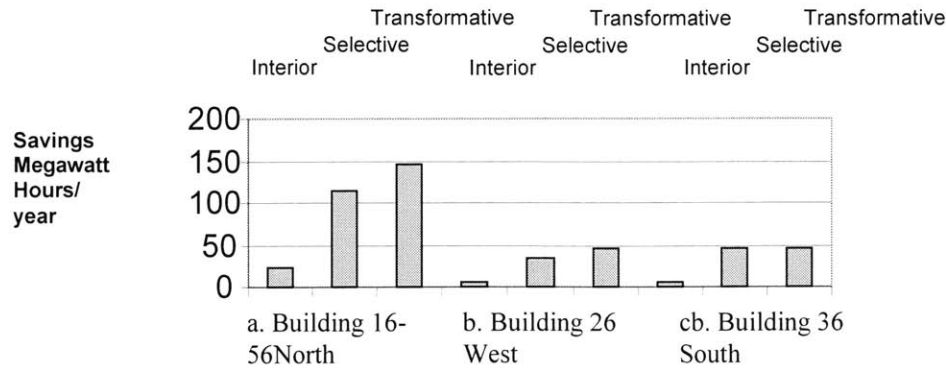


Fig. 42a
Estimated
lighting savings
for measures
taken selected
facades

Façade	Retrofit approach	Lighting Electrical Savings (Mwh/year)
a.	Interior	24.0
16-56	Selective	113.4
North	Transformative	145.0
b.	Interior	7.1
26	Selective	34.7
West	Transformative	44.7
c.	Interior	7.1
36	Selective	45.0
South	Transformative	45.0

Table. 10
Electrical
Demand
reduction as a
result of façade
retrofitting on
selected facades

The investigation of daylight enhancing measures show how the curtain wall may be reconfigured (replacing the spandrel section with a shaped light shelf). This opportunity does not exist with the other façade types due to the overhang or the limitation in width of the punched opening. This table indicates that the combination of a deep floor plan with façade type which is already advantaged for daylight sets up a good opportunity to intervene with daylight enhancing façade measures.

As the façade surface area increases, presumably there would be an economy of scale, causing the capital cost per façade unit for transformation to fall. For these reasons, the North-facing façade of building 16-56 represents an opportunity to reducing campus electrical demand for lighting and improve the working environment of hundreds of students and faculty. This façade design (steel curtain wall) is quite common, and other buildings which have the same set of issues, (i.e. corrosion, heat loss, and water leakage) represent a special opportunity for renewal.

The south facing façade (fig. 39b. note c) and south west facing façade (fig. 39a note a) offer an opportunity for a selective approach. As indicated in Table 3, the flush frame and in fill has good access to daylight, and there is a possibility of pushing light deep into the floor

plan with shaped shelves and redirecting blinds. Two special considerations are the advanced decay of the wood fixing systems and the concern over heat gain. Both of those factors may lead in the end to a transformative approach which allows the stabilization of the wooden fixing system and the addition of blinds outside the glass in a ventilated cavity.

Similar curtain wall and flush frame systems are also opportunities for this approach. The addition of the second layer protects the existing wall from continued wetting and drying cycles, while protecting the daylight enhancing elements from dust and allowing for the escape of unwanted heat gain.

4.5 Transformative prototypes

The following discussion describes two prototype transformations of aging façades that were developed with guidance from the above analysis. One is suitable for north facing façades and areas of obstruction. The other is more suitable for the southern façades. This effort is intended to illustrate the architectural aspects of the transformative upgrades described above.

The first prototypical façade system is designed to take the place of the weathered 1950's era curtain wall (type a). Rather than wasting the materials embodied in the initial construction, the new façade utilizes the existing components and combines them with a glass rain screen. The rain screen keeps moisture away from the refurbished air seal at the existing façade and protects the daylighting components from dust.

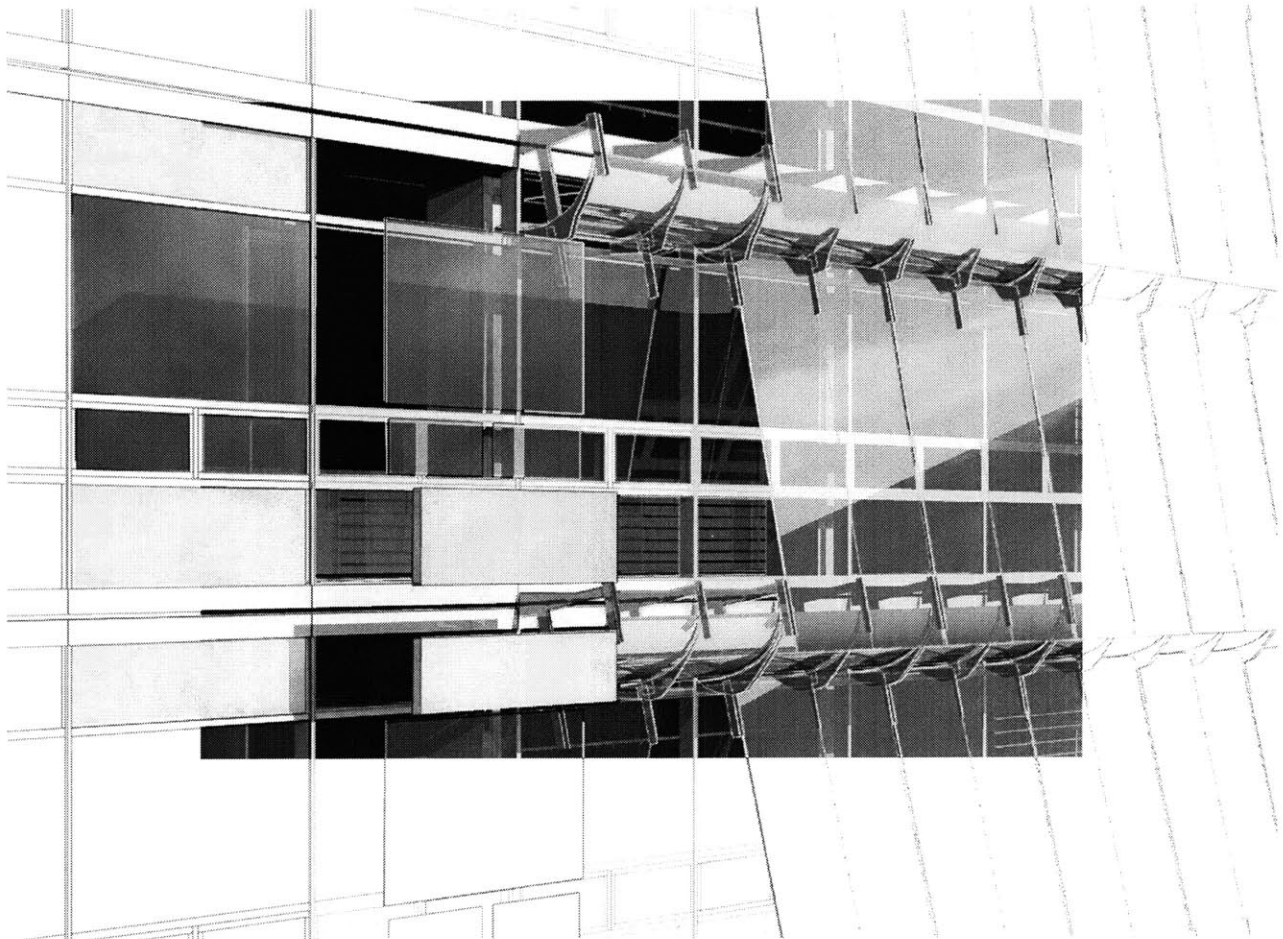


Fig. 43
Proposal for
transformative
façade type for the
the curtain wall
typology
(a) existing
facade
elements
(b) anidolic
shaped light
shelf
(c) outer glass
panels

In addition to a higher degree of transparency, the façade adds an anidolic reflector on the exterior. Anidolic or “non imaging” geometry ensures that there is no distracting sun image on the interior. First developed at EPFL in Switzerland, this shaped light shelf is able to reflect diffuse light at high degrees of efficiency compared to standard

louvers, and light shelves. It occupies the former spandrel zone, transforming the area into a light duct. Since this reflector is operable, it can rotate into a vertical position, on days when there is too much sun in order to reduce the amount of light entering the room, and to ensure that the façade is well ventilated to the exterior.

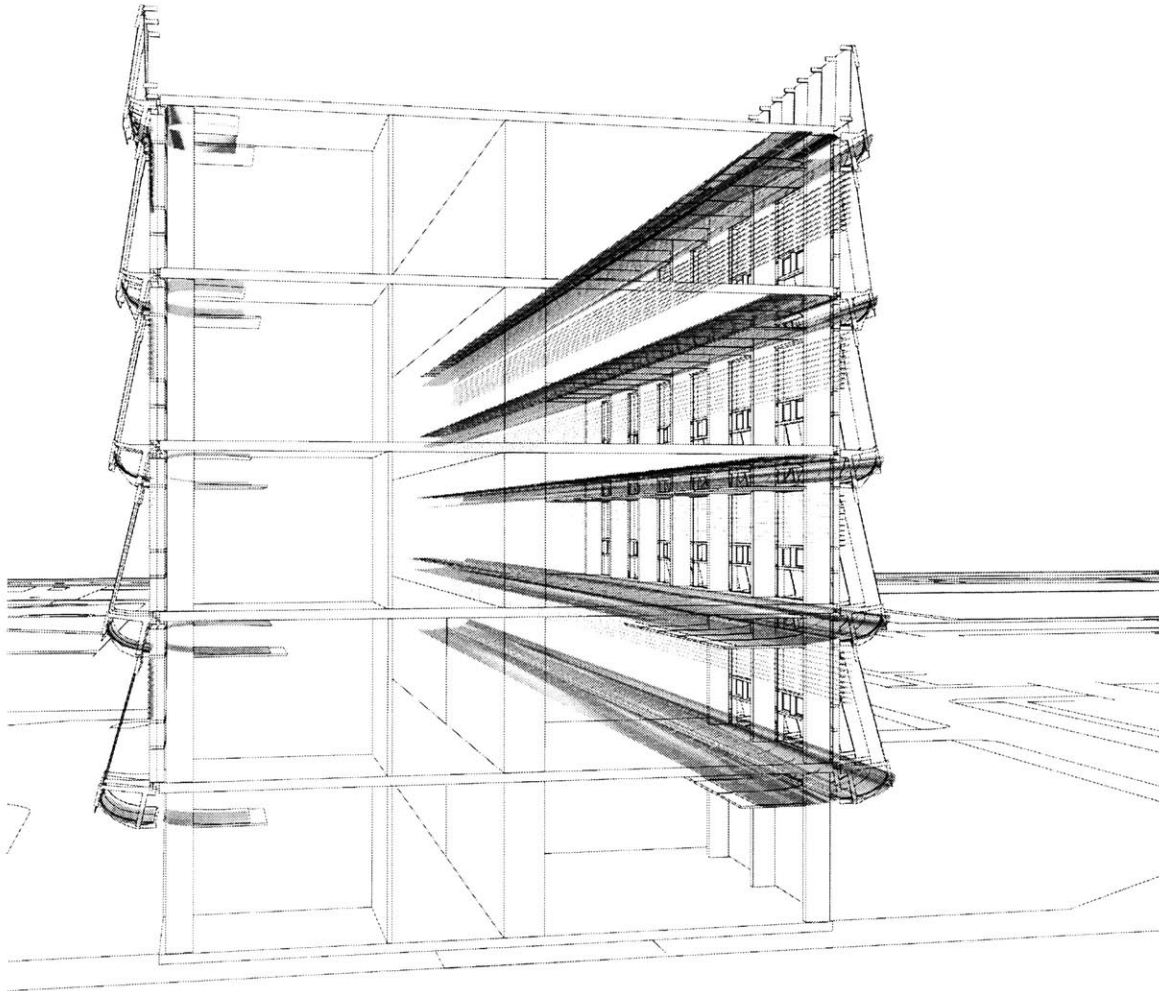


Fig. 44
Rendering of retrofit showing how dimensions of the reflector elements might increase according to the amount of annual available light.

In the winter, when there are more overcast skies and lower temperatures, the reflectors remain open for longer periods. In an urban location with a lack of available light, this system is able to gather light from the zenithal region, where the sky has greater luminance throughout the year. The system is also able to enhance daylight during cloudy conditions. This allows an increase in daylight autonomy. The size of the reflector can be increased with lower levels of annual light availability. This type is scalable in the horizontal and vertical directions, and also would enable natural ventilation to occur even in periods of high wind and rain.

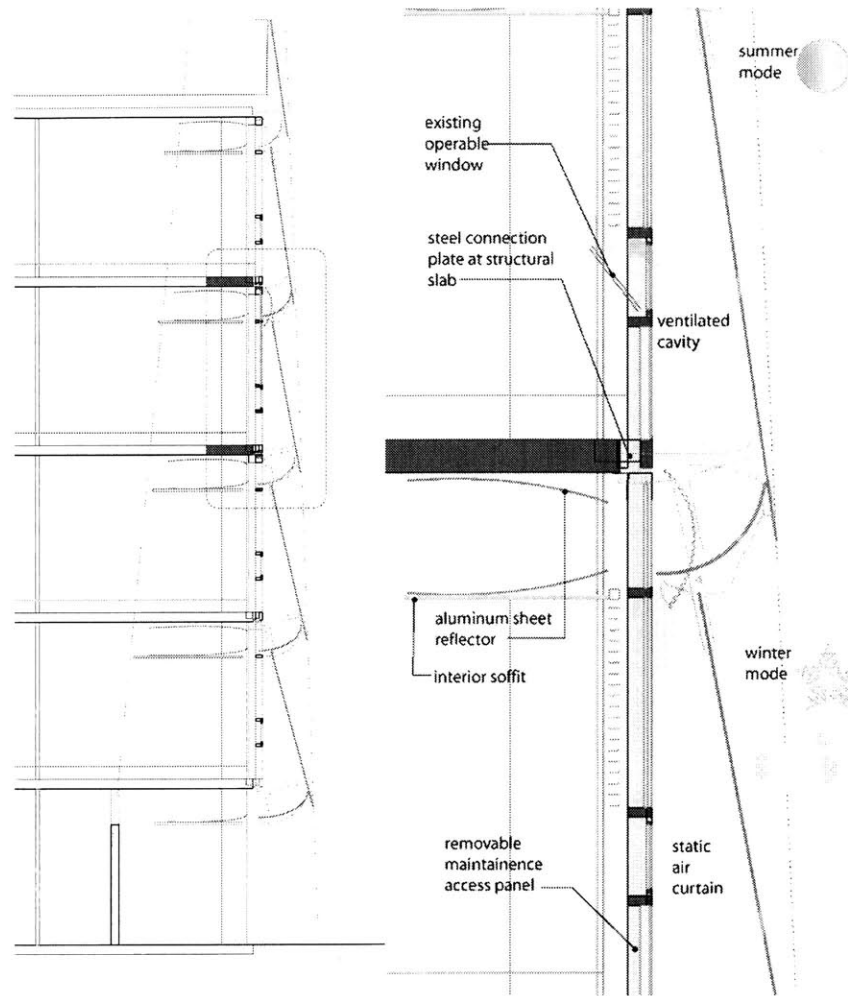


Fig. 45
Wall Section
and section
detail

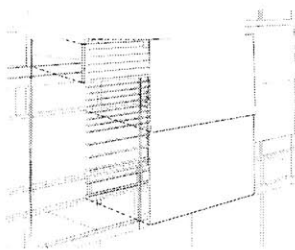


Fig. 46
“Add-on” Retrofit
assembly

The second prototype is designed for the southern façades where the largest concern is to maintain a high degree of transparency while allowing for maximum control. Unlike the previous example, it is suitable for both concrete frame and curtain wall attachment. This prototype has the best daylight utilization improvements for spaces that are deeper than the first two zones, because of the automatic reflective blinds. The system is a partial double skin façade which allows for ample outside air ventilation in the summer (each module is well ventilated on all four directions). The outer layer serves to protect the automated blind system, which is specular. The louvers are larger and more robust than the interior type, and have been coated with a dust repelling material. It should be noted that removal and service of the blinds is accomplished from the removable spandrel panel on the interior. In the winter mode the spandrel allows for a winter-time intake of pre-heated fresh air.



Fig. 47
Rendering of
“add-on”
prototype

4.6 The future of new metrics for daylight

These remarks are aimed more generally at the design community, in an effort to reveal the strengths and difficulties of using advanced metrics in the planning process. This work used new metrics to consider blinds, direct light utilization, and reduction of electrical lighting in a discussion of façade renewal. The issues of urban light access and degree of obstruction have been addressed previously by the daylight factor, but daylight autonomy simulations allowed more sensitive comparisons of these issues to be performed by façade orientation. At the same time, daylight autonomy calculations remain difficult to produce without the aid of an expert. Further, accurate simulations can be very time consuming.

Despite the simplicity of daylight factor calculations, daylight is still often overlooked, even in environmentally-oriented design. In a recent

report on the LEED checklist, it was observed that the 1 point credit for daylight achievement is claimed by only about 60% of LEED registered buildings [Paladino 2004]. The reality is that even amongst buildings claiming a “green” status, only a fraction of those are able to claim a minimal contribution of daylight in the workplace. This is apparent even as lighting can represent 30% or more of all building operational electrical energy. [CBECS 2003] In the northeast, electrical prices are amongst the highest in the US. Since there is no direct connection with the daylight factor and electrical savings, there is a risk that buildings will achieve Platinum ratings while missing a large opportunity to save electrical energy by designing towards daylight autonomy.

In the meantime, in producing a retrofit concept for the building envelope, the designer is left with the highest financial, aesthetic, and environmental liabilities. In a typical new institutional project, the building envelope may comprise as much as 40% of the total cost of construction. Corrosion resistant metals, fixing components, and complex glass manufacturing methods represent the majority of façade cost. The agent of renewal—the in-house architect or planning staff or contracted consultant in most cases—must establish expectations for daylight utilization. It is an important responsibility of the research field to provide a metric that can accommodate the spatial issues of planning and architectural design while at the same time provide a quantitative assessment of the energy saving potential of design solutions. This work demonstrates how daylight autonomy and electrical energy savings metrics can assist in façade renewal decisions.



Fig. 48
Over Midtown
Photo: ER

Climate change has brought a global mandate to decrease building energy consumption dramatically in the existing building stock. Without consistent performance metrics, there is a risk that façade renewal will not capitalize on the opportunity for enhanced daylight and existing buildings will not be transformed, but destroyed in favor of energy-intensive new construction. There is also the more visible risk that “high-tech” façades will remain merely an aesthetic symbol of technology, rather than an adaptive course for architecture and facilities renewal. Well-chosen metrics like daylight autonomy, which capture the value of improved daylight utilization, may be essential in helping the architectural community move toward saving energy and improving the natural lighting in this country’s large and aging building stock.

Appendix A:

Additional Notes on Transformative renewal

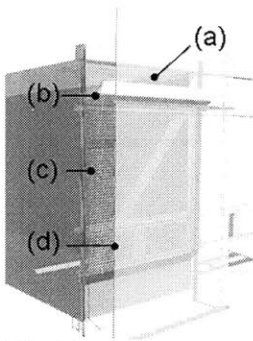


Fig A1:
Transformative
changes

- a. opening of
spandrel zone
- b. shaped light shelf
- c. blind system or
fixed louvers
- d. protective outer
layer of glass

There have been some promising developments in façade design materials in recent years. Multi-layer, multi leaf façades began with the first implementation of insulated glass. Double skin façades improve thermal comfort by allowing unwanted solar gains to be evacuated through an interstitial zone outside of the building. Now these systems provide more opportunities to integrate daylight redirection elements in ways that may not have been economically or technically feasible in the past. Movable blinds can be protected from rain, dust and other maintenance concerns. In the future, Miniaturization and specialization of redirection and protection elements will contribute new options. Films or re-directive materials with variable photometric properties may be applied. The first redirecting materials appeared at the United States Patent office 1898. In nearly all cases the materials were intended to deflect materials further into the floor plan. [Koster 2004 p14]

In cases where the building may thicken its façade zone there are opportunities for increasing the façades access to the daylight and provisions for redirecting light with shaped light shelves or for locating the blinds outside of the building weather barrier, decreasing the cooling requirements. The author acknowledges that the internally ventilated buffer zone is an alternative to this scheme, but might be considered less likely due to the required retrofit of mechanical ventilation inboard of the original weather barrier.

The possibility of maintaining activities during the operation (construction process) can be decisive in the final choice of a strategy.
[Rey 2004 pp1.2]

The transformative approach could also assume that luminaries are integrated with the façade, enabling a removal of the ceiling fixture in the first 3m lighting zone. This change includes a utilization of the daylighting elements for even distribution of the light. The removal of ceiling fixtures in the day lit ceiling area allows better distribution of daylight to the deeper zones in the room. The location of the fixture in the buffer zone permits it to operate without contributing to the cooling load in the summer.

There is also the possible conflict with building codes in extending the building envelope beyond its former extent.

“Shading devices are not encouraged by current regulations- window surround exceeding 10 cm from the face of the external wall are not included in building area calculations.”

[Leng Pp21]

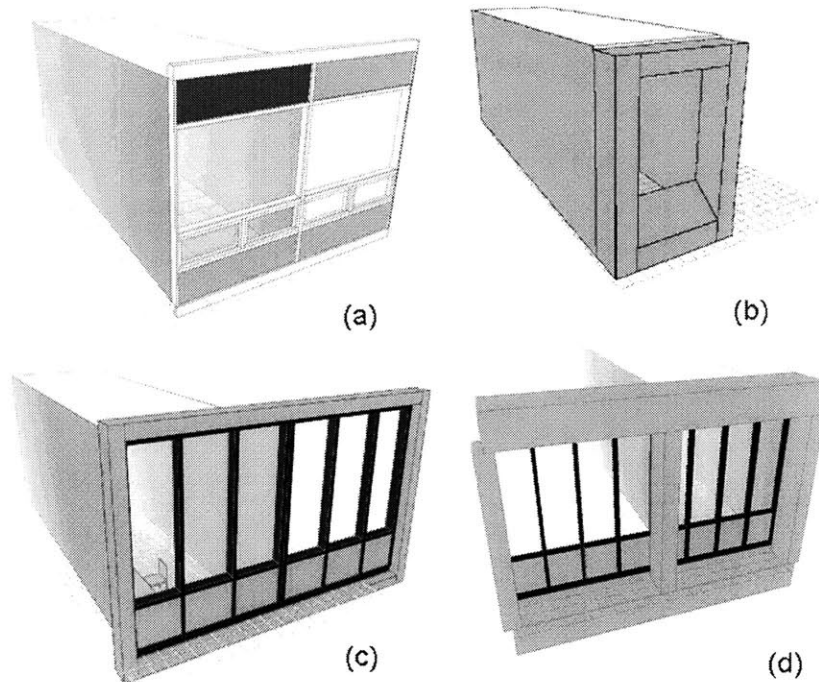
Last and not least there is the qualitative consideration from the exterior:

“In accordance with its degree of performance (energy, comfort, costs, etc.), notably in the case with the suspended glass façades, the double skin strategy can offer an interesting alternative, which subtly allies the conservation of the original substance and the metamorphosis of the building image.”

[Rey 2004]

Appendix B:

Detailed descriptions of MIT Modern Façade Types:



A. Curtain Wall

There are two distinct types existing on three buildings. Buildings 16 and 56 together represent 67% of the area used was a hollow steel mullions and window frames, plate glass, and metal pans spandrel panels filled with insulation. Building 26 represents the remaining 33% of the area and was designed by the more notable Gordon Bunshaft of SOM and differs from 56 and 16 in two critical ways. First, is the used of aluminum trim over a steel system underneath.

The most important result of the difference is that 26 has moisture penetration problems and has presented an ongoing challenge to maintainers. Sealants applied from the exterior are subject to increased weathering and may not prove to be effective long-term solution. A priority for the institution is the evaluation of building 26. The selective replacement of glass with insulated glass is not dimensionally possible, likewise the selective replacement of elements, spandrel panels,

cover plates, will not address the main shortcomings of the system: ability to shed water, and release water from its cavities, and the progressive corrosion of steel fixing components within and steel spandrel panels.

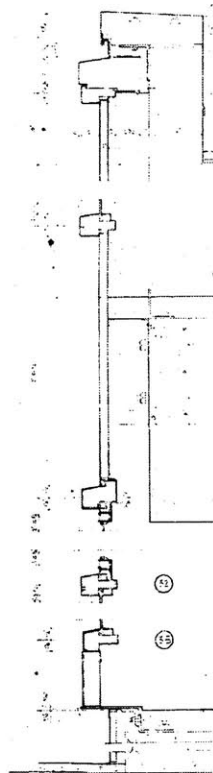


Fig A2: Building 16. Curtain wall section Typical for 16 and 56 Note that mullion accommodates insulated glass which was replaced from the interior[from MIT Facilities archives]

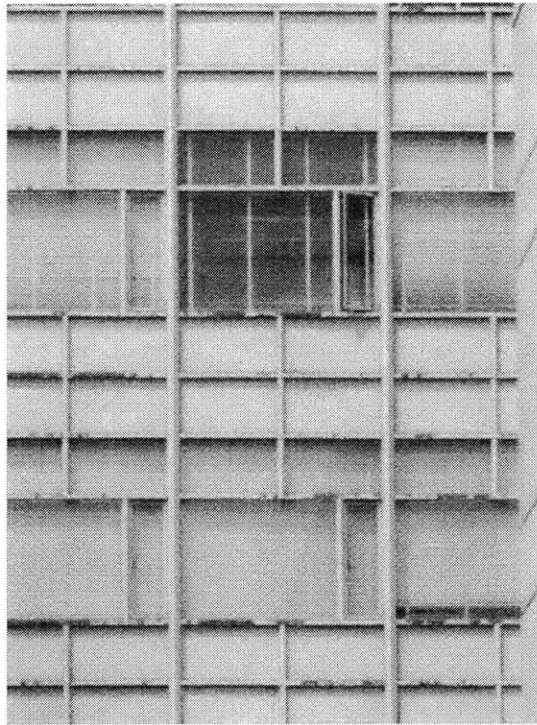


Fig A3: Building 16-56 showing peeling of paint, exposed prime coat, and initial corrosion [photo: ER]

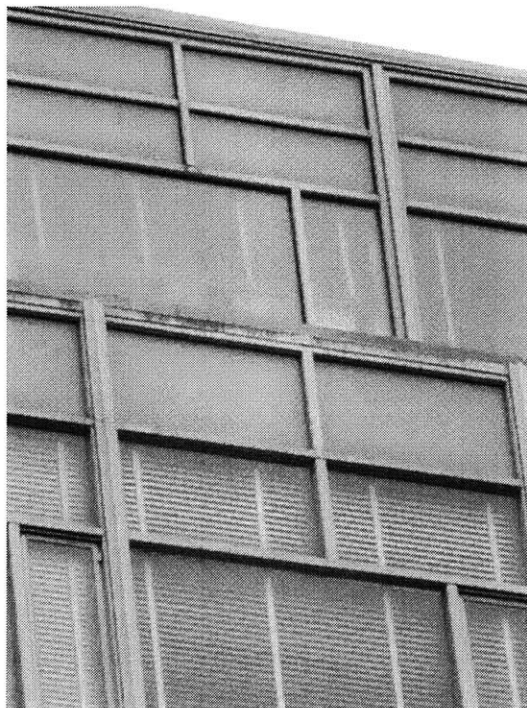


Fig A4: Building 16 North elevation at 8th floor set back showing initial corrosion [photo: ER]

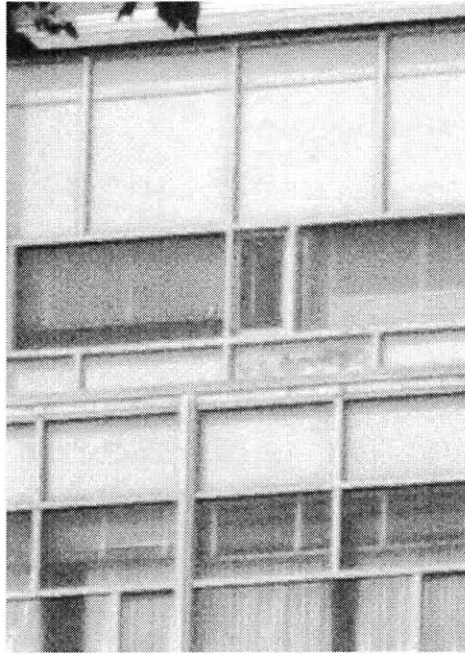


Fig A5: Building 16: South elevation 8th floor corrosion showing on spandrel panel [photo: ER]

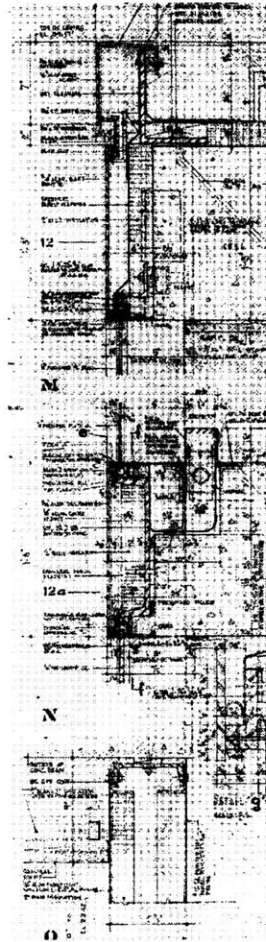


Fig A6: Building 26.1 [from MIT Facilities archives]

B. Punched Openings

Punched openings are apparent on the concrete buildings 54, 6 W53 and also building 48. In the Pei buildings, the system consists typically of plate glass directly glazed into concrete surround, with a removable wood sill in some instances. Replacement of this system is difficult due to the limited sizes of manufactured insulated glass and the dimensional limitations of the glazing recess cast into the concrete. In contrast, at building E53 the removable frame surrounds the window on the interior, facilitating the possibility of a glass retrofit. At building 48, the glass is captured by neoprene gasketing, which is then captured in a steel glazing channel in concrete masonry surround.

Building 54 has lost 2 windows in 43 years of service, both attributed to projectiles and not to failures in the fixing system or glass itself. This is a testament to longevity of glass itself, particularly monolithic glass without applied films. The hermetic seals of early insulated glass units would have failed over that time period.

Run off from concrete contains alkalis that can etch (a permanent marking) the glass over time. This is more apparent on buildings such as E53 which do not have drip edge incorporated into the concrete surround.

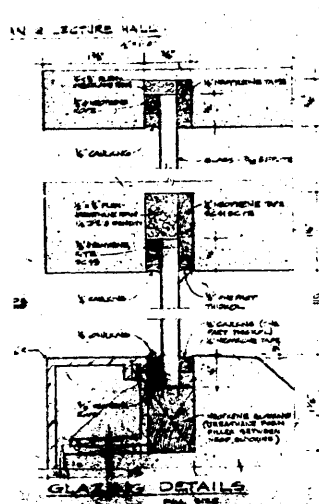


Fig A7: Building 54 Glazing details [from MIT Facilities archives]

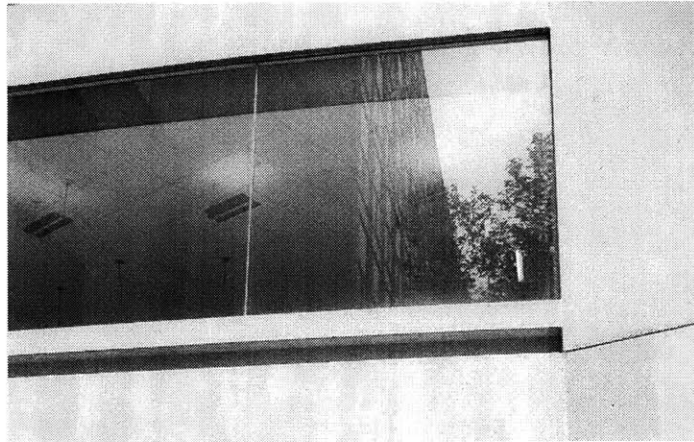


Fig A8: Building 66: Recessed glass on west elevation

C. & D. Frame and In-fill and Exo-frame and In-fill

An important distinction can be made between those which are glazed from the exterior or and those from the interior. In the first case, the glass is fixed in place by a wood batten, attached from the weather side initially with nail fasteners. This was done on building 36 and 38 and comprises 53,000 SF or 43% of the total area of the wood storefront. This portion is in the worst condition. (See Figs below 5). The rapid deterioration of these areas may be due in part to their increased exposure to the weather (note the shallow recess of the glass plane behind the concrete frame as compared to the façade of building 37), and the tendency of smaller sections of wood to warp and check after prolonged wetting and drying cycles. The effects of weathering are not limited a particular face. The integrity of the glass fixing on the exterior poses the greatest risk to occupancy groups and the institution alike.

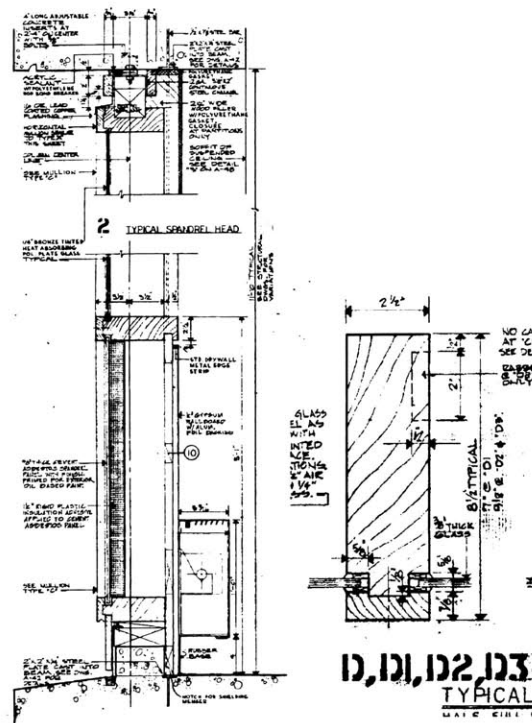


Fig A9: Building 36. Detail at typical Window and spandrel panel and typical Wd. Mullion with outside batten attached with finish nails [from MIT Facilities archives]

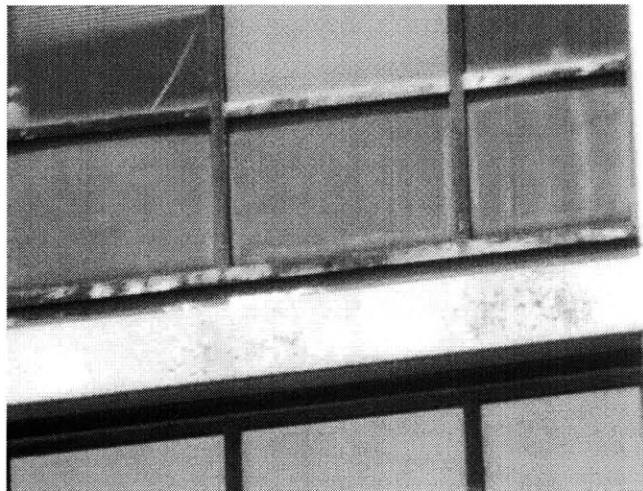


Fig A10: Building 36: N. Elev 3rd Fl.
Deterioration of wood battens [photo: ER]

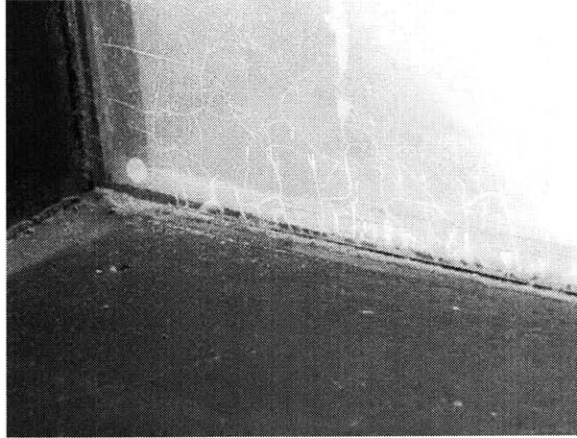


Fig A11: Building 36 N. Elev 3rd Fl. Stairwell interior showing deterioration of applied film [photo: ER]



Fig A12: Building 36 North elevation showing difficulty in matching the metallic coatings with replacement glass- and weathering of early metallic coatings [photo: ER]

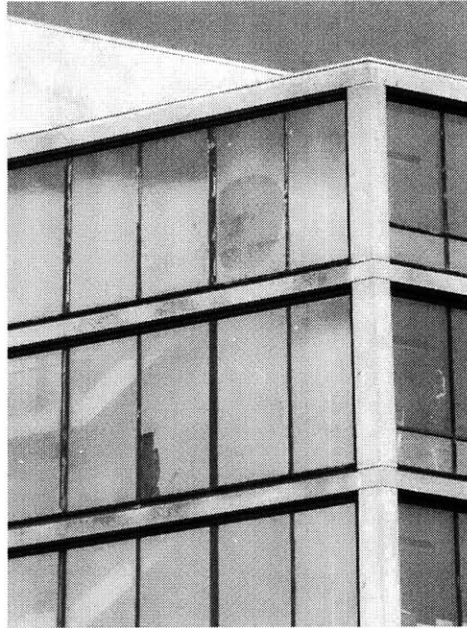


Fig A13: Building 36 Northwest elevation:
de-lamination of interior applied reflective films [photo: ER]

Measurements of transmittance of existing glass:

Building		Exterior (lux)	Interior (lux)	Average trans
26	Solex 6mm	4710	2960	62%
36	Solar bronze	6180	2902	47%
39	Solar bronze	7040	2045	29%
54	Brown body tint	2336	1260	53%

Appendix C:

Detailed Simulation parameters:

Daysim simulation setup:

Weather file: Boston_USA.epw file available from energy plus website

Latitude: 42.35 Longitude: 71.07 Time Zone: 75

Ground reflectance factor: 0.2

Site Elevation. 6.0 M

Data Time step: 1 hour

For Retrofit Scenarios:

Ambient Bounces: 5

Ambient divisions: 1000

Ambient super-samples: 100

ambient resolution: 300

ambient accuracy 0.2

limit reflection: 6

specular threshold: 0.1500

specular jitter: 1.000

limit weight: 0.0040000

direct jitter: 0.0000

direct sampling: 0.200

direct relays: 2

direct pretest density: 512

Radiance Material assignments:

Floor:

void plastic 0 0 5 0.3 0.3 0.3 0.0000 0.0000

Upgraded Floor:

void plastic 0 0 5 0.6 0.6 0.6 0.0000 0.0000

Base case walls:

void plastic 0 0 5 0.5 0.5 0.5 0.0000 0.0000

Upgraded Walls:

void plastic 0 0 5 0.8 0.8 0.8 0.0000 0.0000

Ceiling:

void plastic 0 0 5 0.8 0.8 0.8 0.0000 0.0000

Upgraded Ceiling:

void plastic 0 0 5 0.9 0.9 0.9 0.0000 0.0000

Daylight in façade renewal.

Existing glass:

void glass 26_Glass 0 0 3 0.5 0.5 0.5

Upgrade glass:

void glass 26_Glass 0 0 3 0.75 0.75 0.75

Existing aluminium mullions:

void plastic Aluminum 0 0 5 0.9706 0.9706 0.9706 0.0000 0.0000

Existing spandrel Panel

void plastic spandrel 0 0 5 0.6590 0.6590 0.6590 0.0000 0.0000

References

[AIA 1980]

Predesign Energy Analysis, Department of Energy, 1980
Energy in Architecture Energy in Redesign
1983 Edition
American Institute of Architects

[AIARC 2000]

American Institute of Architects research Corporation
Also Referenced on
http://www.architecture2030.com/building_sector/bldg_sector3.html

[Arons 2000]

Arons, Daniel, *Properties and Applications of Double skin Building
façades*, MIT Thesis 2000

[Battles 2000] Stephanie J. Battles, Eugene M. Burns, *Trends in
Building-Related Energy and Carbon Emissions: Actual and Alternate
Scenarios*, US Energy Information Administration1
American Council for an Energy-Efficient Economy
August 21, 2000

[Behling 1998]

Glass: structure and Technology
Edited by Sofia and Stefan Behling

[Boonstra 1997]

C. Boonstra *Solar Energy in Building Renovation Series*
September 1997 James & James Publishers
ISBN 1-873936-74-5 Solar Energy in Building Renovation by C.
Boonstra and I. Thijssen, W/E Consultants, Sustainable Building, Gouda,
The Netherlands.

[Burton 2001]

Simon, Burton; Marco Sala 2001
Energy Efficient Office Refurbishment, ISBN 1 902916 01 8
James and James Ltd.
London

[CBECS 2005]

U.S. Energy Information Administration statistics
Official Energy statistics of US Government
The Commercial Buildings Energy Consumption Survey (CBECS)

[CBECS 2003]

U.S. Energy Information Administration statistics

Official Energy statistics of US Government

2003 Commercial Buildings Energy Consumption Survey—Overview of Commercial Buildings Characteristics

[Chutarat 2001]

Chutarat, Acharawan

Experience of Light: The Use of an inverse method and a Genetic algorithm in Daylight design. Phd Dissertation MIT September 2001.

[Compagno 1999]

Compagno, Andrea, *Intelligent glass façades*, Birkhauser, ISBN 3-7643-5547-6

[EIA 2006]

Energy Information Administration, US government

Electric sales revenue and price for 2004-2006

http://www.eia.doe.gov/cneaf/electricity/esr/esr_sum.html

[Evans 1998]

Evans Raymond; Haryott, Richard; Haste, Norman; Jones, Alan

The Long term Costs of Owning and Using Buildings

The Royal Academy of Engineering

London

<http://www.raeng.org.uk>

[Kischkoweit-Lopin 2002]

Kischkoweit-Lopin, Martin, *An overview of Daylighting systems* Institut für Licht und Bautechnik an der Fachschule, Köln, Germany. Solar Energy Vol. 73 . 2002 Elsevier Science Ltd.

[Koster 2004]

Helmut Koster, *Dynamic Daylighting Architecture, Basics Systems, Projects*

Birkhauser 2004

[Lang 2001]

Lang, Werner

Is it all just a façade? The functional, energetic and structural aspects of the building skin

Gebäudehüllen. English.

Title Building skin: concepts, layers, materials / Christian Schittich (ed.)

[translation (German/English): Peter Green, Elizabeth Schwaiger].

[Leng 1993]

Woo Pui Leng, *Thick Façades in Hong Kong*, *Revista internazionale di Architettura, Space & Society*, 74 Gangemi Editore 1993

[Mardaljevic 2003]

John Mardaljevic, *Irradiation mapping of complex urban environments: an image based approach*

Energy and Buildings 35 (2003) 27-35

Institute of Energy and Sustainable Development

Elsevier

[MEC 2000]

Massachusetts Building Energy code

Federal Register -Vol. 65, No. 195 -Friday, October 6, 2000 - Rules and Regulations

AGENCY: Office of Energy Efficiency and Renewable Energy, DOE.

[Nabil 2005]

A. Nabil and J. Mardaljevic. Useful daylight illuminance: A new paradigm for assessing daylight in buildings. Lighting Research and Technology, 33 (1), 2005.

[Paladino 2004]

Tom Paladino, *Driving down the cost of LEED*,

Workshop Thursday March 18, 2004 materials prepared by Paladino and Company Inc. ,

Additional authors: Paul Anseeuw, Mark Cork, Mark Buehrer, Bettina Von Hagen, Glen Gilbert, www.paladinoandco.com

[Reinhart 2000]

Christoph P. Reinhart, Sebastian Herkel *The simulation of annual daylight illuminance distributions – a state of the art comparison of six Radiance-based methods*

[Reinhart 2004]

Christoph F. Reinhart, *Electrical lighting energy savings for an on/off photocell control – a comparative simulation study using DOE 2.1 and Daysim* The lighting group Institute for Research in Construction, National Research Council Canada, Ottawa

[Roaf 2005]

Roaf, Susan, David Crichton and Fergus Nicol

Adapting buildings and Cities for Climate Change, A 21st century

Survival guide

Architectural Press, 2005

[Rey 2004]

Rey, Emmanuel, *Office building retrofitting strategies: multicriteria approach of an architectural and technical issue*, Energy and Buildings 36 (2004) 367-372 Bauart Architectes, Espace de l' Europe 3a, CH

[Selkowitz 2001]

Selkowitz, Steven E
Integrating Advanced Façades into High Performance Buildings
7th international Glass Processing Day, Tampere Finland
Building Technologies Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley Laboratory

[Smith 2003]
Smith, Peter F. *Sustainability at the cutting edge, Emerging technologies for low energy Buildings*
Architectural Press, Elsevier Science
2003

[US DOE 1999]
US Department of Energy, *Carbon Dioxide Emissions from the Generation of Electrical power in the US*, October 15, 1999, Wiley Barbour

[Vigener 2006]
Nik Vigener, PE *Whole Building Design Guide*, Glazing, Simpson Gumpertz & Heger Inc. 2006, National Institute of Building Sciences.
http://www.wbdg.org/design/env_fenestration_glz.php

[Voratz et al. 1997] Voratz, D, L Shown, J Koomey, M Moezzi, A Denver, and B Atkinson. *Lighting Market Sourcebook for the U.S.* December 1997
Lawrence Berkeley National Laboratory

[Walkenhorst 2002] Oliver Walkenhorst, Joachim Luther, Christoph Reinhart, Jens Timmer, *Dynamic annual daylight simulations based on one hour and one minute means of irradiance data*, Solar Energy and building Vol. 72. 5, pp. 385-395, 2002 Elsevier

[Ward, 1998] Greg Ward Larson and R. Shakespeare. *Rendering with Radiance: The art and Science of Lighting Visualization*. San Francisco: Morgan Kaufmann, 1998

Web/Software References

[A] Daysim

Version 2.1, Institute for research in Construction

National Research Council, Ottawa, Canada

Dr. Christoph F. Reinhart

http://irc.nrc-cnrc.gc.ca/ie/lighting/daylight/daysim_e.html

[B] Radiance

Greg Ward Larson and Rob A. Shakespeare

<http://radsite.lbl.gov/radiance/HOME.html>

<http://radsite.lbl.gov/radiance/book/>

[C] Ecotect

Version 5.2

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www.squ1.com

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<http://designadvisor.mit.edu/design/>

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